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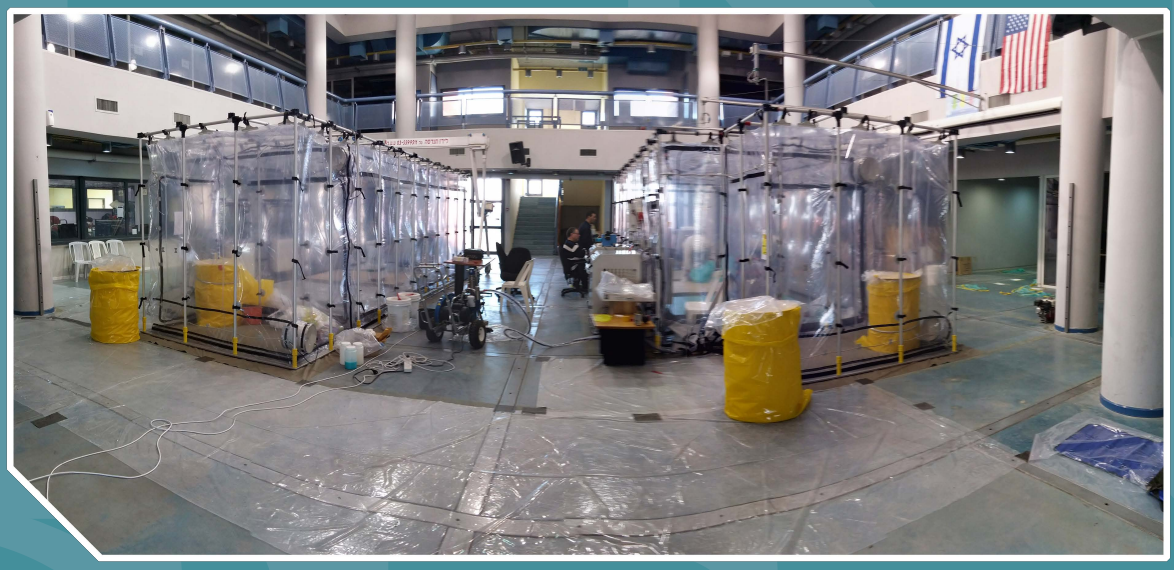
Evaluation of Hydrogel Technologies for the Decontamination of 137Cs from Building Material Surface



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Evaluation of Hydrogel Technologies for the Decontamination of ^{137}Cs from Building Material Surfaces

U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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Disclaimer Statement

This work was conducted under the U.S. Department of Defense (DOD) Technical Support Working Group (TSWG) Task Plan, Number CB.3803-5, with funding provided by U.S. Department of Defense and the Israel Ministry of Defense. It has been subjected to U.S. Environmental Protection Agency (EPA) review and has been approved for publication. Note that approval does not signify that the contents necessarily reflect the views of EPA. Mention of trade names, products, or services does not convey official EPA approval, endorsement, or recommendation.

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Abstract

The U.S. Environmental Protection Agency (EPA) Homeland Security Research Program (HSRP) strives to help protect human health and the environment from adverse impacts resulting from release of chemical, biological, or radiological agents. This current research effort was developed to evaluate intermediate level (between bench-scale and large-scale or wide-area implementation) decontamination procedures, materials, technologies, and techniques used to remove radioactive material from different surfaces. In the event of such an incident, application of this technology would primarily be intended for decontamination of high-value buildings, important infrastructure, and landmarks. A cost-benefit calculation may occur in other cases. Two radioisotopes were tested: aqueous salts of cesium-137 (^{137}Cs) and the short half-life simulant to ^{137}Cs, rubidium-86 (^{86}Rb). The radioisotope technetium-99m (^{99m}Tc) was also used for a preliminary test of the experimental procedures, without full recording of results. Two types of decontamination technology products were evaluated: DeconGel™, a product of Cellular Bioengineering Inc. (CBI); and EAI Supergel, a product developed by researchers at Argonne National Laboratory (ANL), and now manufactured and supplied by Environmental Alternatives, Inc. (EAI) USA. The work was conducted at the assigned Chemical, Biological, Radiological, and Nuclear (CBRN) Israel Defense Force (IDF) home front command facility near the town of Ramla and at the Nuclear Research Center Negev (NRCN), Israel. Experimental setups at the two sites were nearly identical; however, ^{99m}Tc and ^{86}Rb were utilized at the Ramla site, while only ^{137}Cs was utilized at the NRCN site. Results from these tests indicated similar percent removal values, %R, and operational factors for both ^{86}Rb and ^{137}Cs. This was predicted based on the similar chemical properties of both elements. These results further showed that the short half-life radioisotope ^{86}Rb can be used in future experiments to simulate ^{137}Cs. Results obtained and conclusions drawn from these experiments appear in this report, and are compared to previous parameters calculated during EPA's experiments on small coupons.

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Abbreviations/Acronyms

A_f	Final activity
A_i	Initial activity
ANL	Argonne National Laboratory
AVR	Average
^oC	Degree(s) Celsius
CBI	Cellular Bioengineering, Incorporated
CBRN	Chemical, Biological, Radiological, and Nuclear
Co	Cobalt
cpm	Counts per minute
cps	Counts per second
Cs	Cesium
dB	Decibel
DOD	U.S. Department of Defense
DSP	Digital signal processor
EAI	Environmental Alternatives, Inc., USA
EPA	U.S. Environmental Protection Agency
HEPA	High-Efficiency Particulate Air
hr	Hour(s)
HSRP	Homeland Security Research Program
IAEC	Israel Atomic Energy Commission
IDF	Israel Defense Force
keV	Kiloelectron volt(s)
kg	Kilogram(s)
L	Liter(s)
lb	Pound(s)
m	Meter(s)
µCi	MicroCurie(s)
mCi	MilliCurie(s), 1 mCi = 3.7×10^7 Bq = 3.7×10^7 dps
min	Minute
min/m^2	Minutes per square meter
mL	Milliliter(s)
mm	Millimeter
MOD	Ministry Of Defense (Israel)
MPa	Mega Pascal(s)
NH_4Cl	Ammonium chloride
NaI(Tl)	Sodium iodide with thallium activator (a crystal used as an alkali halide scintillation detector)
NRCN	Nuclear Research Center Negev (Israel)
Pa	Pascal
ppm	Parts per million
psi	Pounds per square in
%R	Percent removal
RDD	Radiological dispersal device
RH	Relative humidity
Rb	Rubidium

Tc	Technetium
TSWG	U.S. DOD Technical Support Working Group
VAC	Voltage, alternating current (AC) power

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This work was conducted under U.S. DOD Technical Support Working Group (TSWG) task plan number CB.3803-5. The authors of this report would like to thank Israel Ministry of Defense (MOD), Israel Atomic Energy Commission (IAEC) – Nuclear Research Center Negev (Israel) (NRCN), and TSWG for financially supporting this project. Thanks go to Christina Baxter from TSWG and to Esther Krasner from Israel MOD for guidance and support during initiation and performance of the task plan. Last but not least, special thanks go to the professional staff of NRCN's decontamination and radiation safety departments, Argonne National Lab (ANL), and Tetra Tech, Inc. (Tetra Tech), a contractor with the U.S. Environmental Protection Agency (EPA). This work would not have been possible without their commitment to this project.

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1.0 Introduction

The U.S. Environmental Protection Agency (EPA) Homeland Security Research Program (HSRP) strives to help protect human health and the environment from adverse impacts resulting from release of chemical, biological, or radiological agents. With emphases on decontamination and consequence management, water infrastructure protection, and threat and consequence assessment, HSRP is working to develop tools and information that will aid cleanup of chemical or biological contaminants introduced into buildings or water systems.

The U.S. Department of Defense (DOD) and the Israel Ministry of Defense (MOD) are jointly engaged in a project to study procedures for cleaning up contaminated areas—primarily high-value buildings, important infrastructure, and landmarks following a radiological dispersal device (RDD) event. Results from this project would apply to any wide-area radiological contamination incident. The project is led by the U.S. DOD Technical Support Working Group (TSWG) and Israel MOD, with participation of EPA and experts from the Israeli Nuclear Research Center Negev (NRCN).

To prepare for a possible radiological attack, evaluations of the capability to decontaminate critical infrastructure, such as transportation (Yaar and others 2015), drinking water systems, power, communications, medical services, and essential government services, are necessary. Currently available decontamination technologies must be evaluated for performance on a range of surfaces that might be contaminated following a wide-area incident. This evaluation must go beyond the bench scale to ascertain whether the tested technologies will be effective.

Despite some commonalities in a typical RDD scenario, regardless of type of radioisotope involved, each isotope differs in aerosol particle size and distribution after a release (Harper, Musolino, and Wente 2007) and in bonding strength to the surface examined. Therefore, every isotope exhibits different properties that directly and significantly affect selection and implementation of the best performing and safest decontamination material and technique, as demonstrated in tests by EPA and others. Furthermore, other variables and factors related to radiological dispersion and individual building construction are significant in determining location, concentration, total volume, and associated activity levels of contamination, and of course, selected decontamination methods and materials (Drake 2013c)

A radiological incident can disperse radioactive material over a large geographic area. All surfaces and environmental media where the dispersed material settles would become contaminated. Radioactive material could also be deposited on exterior surfaces such as sidewalks, roofs, streets, sides of buildings, vehicles and equipment, and on interior surfaces via ventilation systems, open doors and windows, and pedestrian tracking. Surface deposits such as fine particulate matter may be removed easily or may adhere to surfaces. Loose surface contamination could be resuspended, transported, and redeposited elsewhere by physical interaction, wind, or precipitation. Moreover, sanitary or storm sewers can become contaminated by runoff from precipitation, leading to subsequent contamination of waterways. Contamination can become fixed if bonded to or embedded

in the affected surface (in pores, cracks, or crevices). This embedded material would be more difficult to remove but would be less likely to present an ingestion or inhalation hazard unless it became disturbed or dislodged. The information in this report addresses removable surface contamination. In the past few years, EPA has evaluated performances of several peelable/strippable coatings for radioactive material decontamination. The major differences between this test and the studies conducted previously pertain to size of test surfaces and use of rubidium-86 (^{86}Rb) as a simulant for cesium-137 (^{137}Cs). Use of larger surfaces (1.5 by 2 meters) allowed for a more accurate evaluation of the time and effort needed to perform a large-scale decontamination effort. Use of the short half-life radioisotope ^{86}Rb (18.6 days) instead of the medium half-life radioisotope ^{137}Cs (30 years) allowed the experiment to be conducted outside of a controlled nuclear facility and evaluation of the use of ^{86}Rb as a simulant to ^{137}Cs for future large-scale decontamination experiments.

Testing included application of radioactive contamination to surfaces, measurement of radiation contamination present on surfaces, application and removal of two types of decontamination technologies (gels), and subsequent measurement of residual contamination to determine efficacy of each gel for removal of the contamination.

2.0 Experimental Details

2.1 Test Program 1

The experimental program plan for the initial test at Ramla and NRCN appears in Appendix C. As shown in Appendix C, parameters tested in both places were the radioisotope type (^{86}Rb or ^{137}Cs), surface type (concrete or ceramic), decontamination gel type (DeconGel™ 1120 or Environmental Alternatives, Inc., USA [EAI] Supergel), and time period before application of the gel on the contaminated surface (48 or 96 hours).

The tests utilized three isolation chambers (two were positioned at the Chemical, Biological, Radiological, and Nuclear [CBRN] Israel Defense Force [IDF] facility in Ramla, and one was positioned at NRCN). These chambers were used to establish controlled temperature, relative humidity (RH), and airflow conditions; and to prevent spread of radioactive contamination outside the test facilities. Temperature and relative humidity data were acquired by use of the ZICO 9622, 3-in-1 Thermometer, Hygrometer & Alarm Clock [ZICO 2016]. Measurements were taken approximately once per hour. All measurements were taken inside the test facility building and not inside the isolation chambers.

The IsoArk isolation chambers used in this test, depicted on Figure 2-1, were specially designed and manufactured by Beth-El Industries Ltd (Beth-El Group 2015) for this test. Isolation chamber specifications are in Appendix A.

Testing surfaces and materials selected for these experiments, concrete and ceramic, are representative and typical of materials currently used in interiors and exteriors of buildings in terms of quality, surface characteristics, and structural integrity—and typical of those in industrial and municipal settings. The concrete and ceramic test surfaces, shown on Figure 2-2, were manufactured by Tamar Group (Tamar Group 2015) (surface specifications and method of preparation are in Appendix B). Test surfaces were prepared from the same starting materials, following the same preparation procedure as described in Appendix B. A total of eight surfaces, each measuring 1.5 by 2 meters and 0.15 meter thick, were used in the experiments. Six surfaces were used at the Ramla site and two were used at the NRCN site. The surfaces used at NRCN were divided by a small plastic separator to form four surfaces of 1.5 by 1 meter each, in order to increase the number of parameters tested. The surfaces were prepared approximately 2 months before the tests, and were allowed to equilibrate for 6 days under the controlled environmental conditions of the isolation chamber prior to contamination of the surfaces with ^{86}Rb or ^{137}Cs radionuclide solutions. All the surfaces were initially divided into 48 subsectional areas of 0.25 by 0.25 meter each that were preliminarily marked on the surface, as shown on Figure 2-2.

Figure 2-1. IsoArk decontamination isolation chambers

Figure 2-2. Ceramic surface after dividing into 48 subsections of 0.25 by 0.25 meter each

2.2 Radionuclides – Test Program 1

Radioactive ^{86}Rb chloride and ^{137}Cs chloride salts dissolved in water were purchased from a certified supplier abroad and used without further purification. The Technicium-99 metastable (^{99m}Tc) solution was purchased from ISORAD (Isorad Radiopharmaceutical Division 2015) in Israel. Due the short half-life of this isotope, the solution was delivered directly to the Ramla experimental site

on the day of the field test. Total activities of the radioactive solutions applied during the experiment were 100 milliCuries (mCi) of ^{99m}Tc, 100 microCuries (µCi) of ^{86}Rb, and 40 µCi of ^{137}Cs.

To generate identical activities, the concentrated radioactive solutions were divided into identical volumes by use of a micropipette and poured into common household spray bottles containing 300 milliliters (mL) of distilled water per bottle to produce the final solutions used to contaminate the tested surfaces (a different bottle was prepared for every surface). The activity per surface used for every radionuclide is listed below in Table 2-1. Radionuclide contaminants were applied to the test surfaces (three concrete and three ceramic surfaces at Ramla, and two concrete and two ceramic surfaces at NRCN) at staggered time intervals during the day, according to the experimental timetables presented in Appendix C.

Table 2-1. Activity Per Surface used for Every Radionuclide

Radionuclide	Site	Number of surfaces used	Surface size (meters)	Activity per surface*
^{99m}Tc	Ramla	2**	1.5 x 2 x 0.15	50 mCi
^{86}Rb	Ramla	6	1.5 x 2 x 0.15	16.7 µCi
^{137}Cs	NRCN	4	1.5 x 1 x 0.15***	10 µCi

* The listed activity is not corrected for radioactive decay.
** A total of six surfaces were used at the Ramla site. The ^{99m}Tc surfaces were later reused for the ^{86}Rb test.
*** The surfaces used at NRCN were half the size of those used at the Ramla site.

2.3 Radiation Measurements – Test Program 1

Radiation measurements occurred by use of the Rotem Industries, Ltd. (Rotem) RAM-SURF portable contamination meter (Rotem 2015), shown on Figure 2-3; the Universal Detection Technology personal radiation detector PDS-100G/ID (Rotem 2015), shown on Figure 2-4; and a conventional 2-inch (2") thallium-activated sodium iodide (NaI(Tl)) scintillation PM-11 Detector (Rotem 2015), shown on Figure 2-5, connected to a laptop via a digital signal processor (DSP) connection box built by NRCN, shown on Figure 2-6.

Figure 2-3. RAM-SURF portable contamination meter

Figure 2-4. PDS-100G/ID personal radiation detector, connected to a tripod

Figure 2-5. PM-11 2" NaI(Tl) scintillation lead-shielded detector

During the surface measurements, the NaI(TI) detector was shielded with 40 millimeters (mm) of lead from all sides, and with 1 mm of copper from the front. The detector shield was fitted with wheels, and the collimated detector was positioned inside it at a fixed height of 0.25 meter above the scanned area, as shown on Figure 2-5. During the surface measurement, the detector was moved to obtain a detailed map of the surface contamination, according to the 48 individual sub-surfaces of 0.25 by 0.25 meter that were preliminarily marked on the surface, as shown on Figure 2-2.

Figure 2-6. The NRCN signal processor (DSP) connection box

Before every day of measurements, the shielded NaI(TI) detector was calibrated by use of a calibration source. Energy calibration of the detector for the ^{99m}Tc tests involved use of the 140.51-kiloelectron-volt (keV) photo peak in the energy spectrum of this isotope, while energy calibration of the detector for the ^{86}Rb and ^{137}Cs tests involved use of a Cobalt-60 (^{60}Co) source. Typical calibration spectra of ^{99m}Tc and ^{60}Co obtained by this detector at the Ramla site are depicted on Figure 2-7 and Figure 2-8, respectively (the two measurements were taken independently under different detector setups).

In one of the experiments, image-plates [Lee and others 2000] were used in an attempt to obtain a "real" picture of the contamination layout on the surface. While the NaI(Tl) detector measures total activity of a 0.25 by 0.25 meter area, the image-plates provide a detailed layout of contamination distribution within this area.

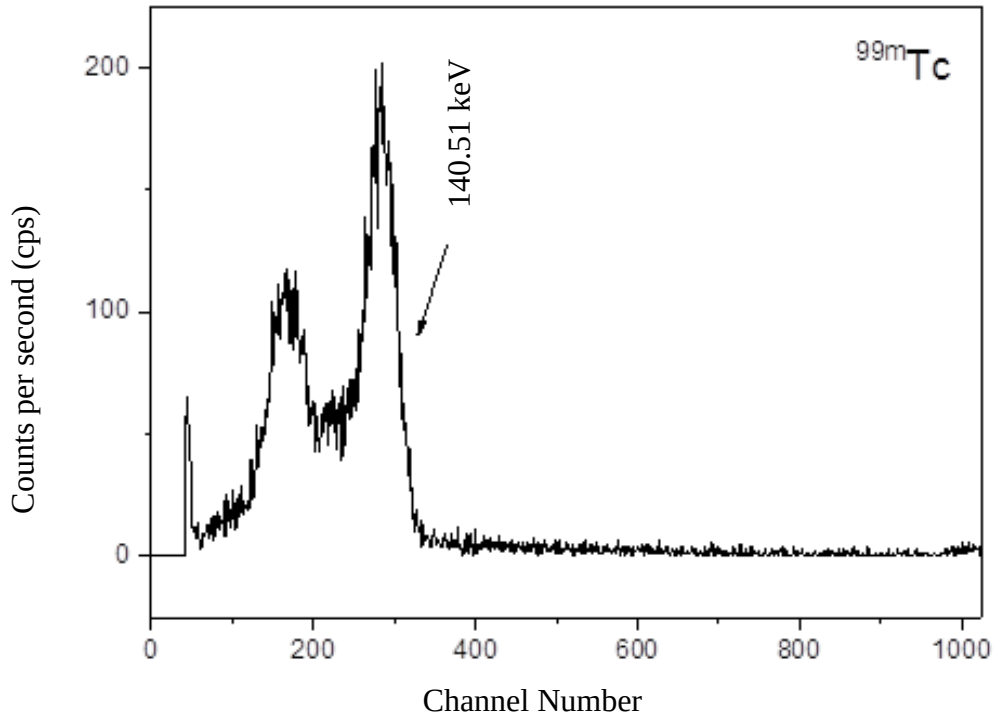


Figure 2-7. PM-11 2" NaI(Tl) scintillation detector calibration chart using a ^{99m}Tc source

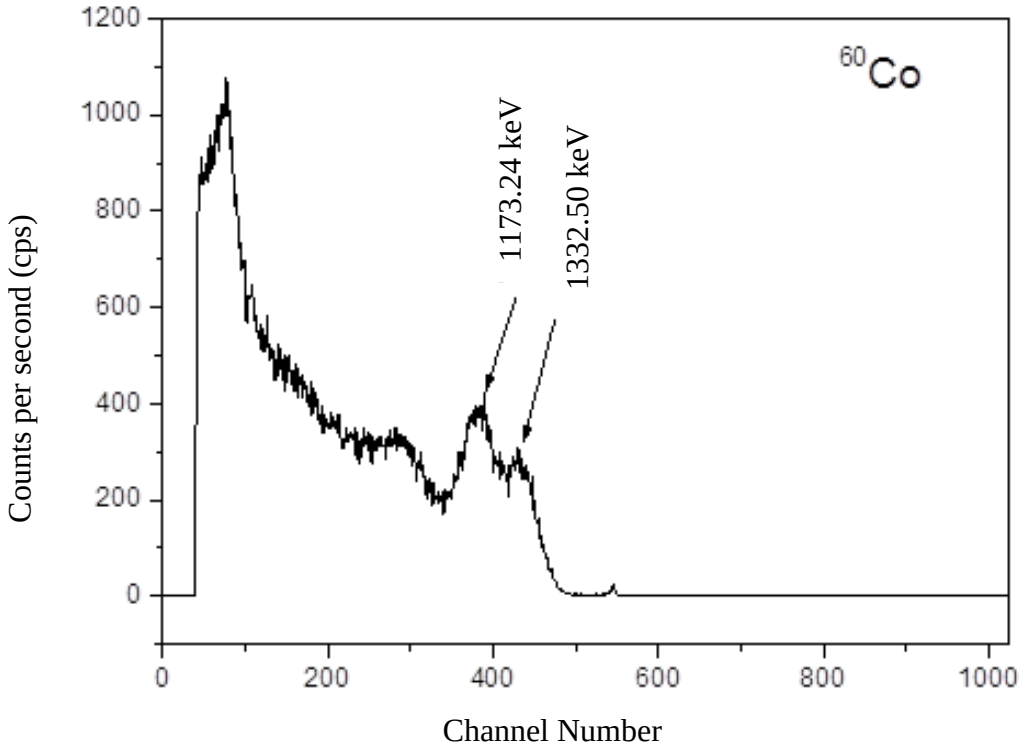


Figure 2-8. PM-11 2" NaI(Tl) scintillation detector calibration chart using a ^{60}Co source

2.4 Decontamination Gels – Test Program 1

Two gels were used in this test: DeconGel™ was used in one Isolation Chamber, and EAI Supergel was used in the other.

DeconGel™, a product manufactured by CBI Polymers, Incorporated (CBI) (Honolulu, Hawaii), is a one-component, water-based, broad-application, peelable, decontamination hydrogel that works by attracting the contaminant, binding to it physically and/or chemically, and upon curing, mechanically locking or encapsulating the contaminant in a polymer matrix. DeconGel™ is available in three versions, or viscosities, each developed for a specific decontamination use on various surfaces and areas. The compound used in these experiments was the DeconGel™ 1120. This product was purchased directly from the supplier as a ready-to-use mix without any dilution.

Drying time finally used for the DeconGel™ 1120 was 48 hours (hr) instead of the originally planned drying time of 24 hr. The longer drying time was necessary due to temperature and humidity conditions during the experiment. The removal process from the smooth ceramics surfaces was fast and easy, while more effort and use of sharp tools were necessary to remove the gel from the more porous concrete surfaces. After removal, the dried sheets of DeconGel™ were packed and disposed of easily. A schematic diagram of the DeconGel™ 1120 decontamination process appears on Figure 2-9.

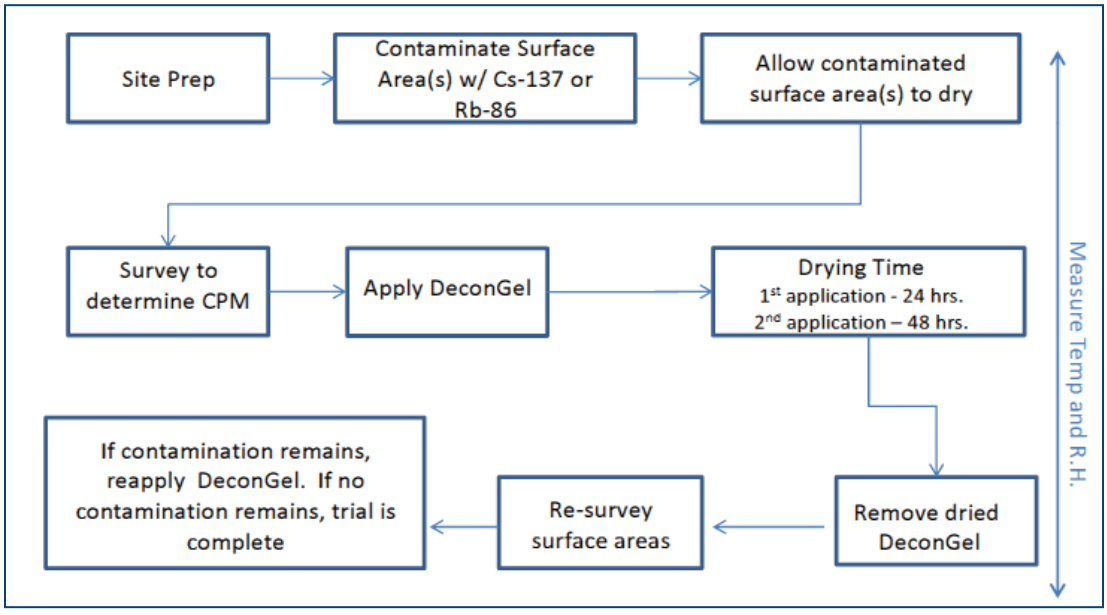


Figure 2-9. A schematic diagram of the DeconGel™ 1120 decontamination process

EAI Supergel, a product manufactured by Environmental Alternatives, Inc. (Clarksburg, Maryland), is a gel system that can clean ^{137}Cs radioactive contamination from porous structures such as brick and concrete on vertical surfaces. The system uses engineered nanoparticles and a superabsorbent

gel to clean buildings and monuments exposed to radioactive materials. Amount of contamination removed depends on characteristics of the contaminated structure: age, type of material, whether painted or unpainted, and the radioactive isotope involved.

The EAI Supergel was purchased as a dry powder. Mixing of the powder with purified water occurred at the site 0.5-1 hour before application of the gel to the surface, per the instructions listed below (for preparation of 4 liters [L] of gel).

1. Place 214 grams of ammonium chloride (NH_4Cl) in a container, and fill to 4 L with deionized water.
2. Slowly add dry gel components (202 grams dry polymers) to the NH_4Cl solution.
3. Use a torque-stirrer, shown on Figure 2-14, at 600 revolutions per minute (min) to mix until the entire dry polymer is hydrated.

Contact time for the EAI Supergel was 90 min, and the gel was removed by use of an industrial vacuum cleaner. The removal process was difficult because after 90 min, some of the gel applied to the concrete surfaces was found to be partly dry. A change in the contact time to 30 minutes was made for the second test program.

Both DeconGel™ and EAI Supergel were applied by use of a hand-held power sprayer with a wide shot tip, No. 531, shown on Figure 2-10. The main electric motor and gel bucket were left out of the isolation chamber, and a long flexible pipe was used to transfer the gel from the sprayer into the chamber. Total volume of the system (sprayer and pipe) was 2 L, and the sprayer and pipe were cleaned with water after every use.

Figure 2-10. The sprayer used to apply the decontamination gel to the surface

2.5 Test Program 2

The experimental program for the second test at Ramla is described in Appendix C. Test Program 2 was run nearly identical to Test Program 1, except for the following changes:

- Only one radioisotope, ^{86}Rb was used for Phase 2 evaluation as compared to three used during the Phase 1 evaluation (^{99}Tc, ^{137}Cs, and ^{86}Rb). Findings from Phase 1 of the experiment demonstrated that ^{86}Rb was an effective surrogate for ^{137}Cs, one of the objectives of the experiment, and ^{137}Cs was therefore eliminated from Phase 2 of the experiment.
- All testing and evaluation during Phase/Test 2 occurred in Ramla at the CBRN IDF facility. No additional testing or evaluation occurred at the NRCN facility.
- Limestone (Jerusalem stone) and marble replaced ceramic as testing surfaces in the Phase/Test 2 evaluation. This change was made because limestone and marble are more prevalent building surfaces in Israel and in the United States, and are also considered higher-value building materials. Construction/fabrication specifications and physical properties of the limestone and marble test surfaces are in Appendix B.
- Test surfaces were placed in vertical standing positions during the decontamination phase of Phase 2, as compared to horizontal positioning used in Phase 1. The change was made because vertical surfaces are more prevalent than horizontal surfaces in an urban

environment, and the purpose of the experiment was to simulate real-world conditions. Application of radioactive contaminant to test surfaces, as well as pre-and post-contamination/ decontamination measurements, occurred while test surfaces were in horizontal position.

- Because of safety concerns regarding vertical standing test surfaces, the test surfaces for the Phase 2 evaluation were constructed in a manner to reduce weight. Each operational test surface had minimum thickness of 25 mm. The surface of interest was mounted on a lighter weight material to ensure structural integrity.
- Total activity of the ^{86}Rb source used in the Phase 2 testing was increased to 1000 µCi, as compared to 100 µCi in Phase 1. This change was made because of the short half-life and natural loss of 3.6% of activity per day, elimination of use of ^{137}Cs in this experiment, and desire to increase the counting rate and reduce the counting statistical error.
- Dwell time for both decontamination technologies on the Rb-contaminated test surfaces prior to removal was 10 min for an area measuring 0.5 by 0.5 meter (total of 12 points per surface), instead of 5 min for an area measuring 0.25 by 0.25 meter in Phase 1.
- Air flow in the isolation chamber was optimized to only slight negativity to avoid drying the decontamination materials too quickly. Specifications of the IsoArk isolation chambers are in Appendix A.
- Phase 2 testing and evaluation of the decontamination technologies occurred during the second week of November 2015, and continued into the third week of November 2015. The Phase 2 experimental timetable is in Appendix C.
- Thermogravimetric analysis on concrete test surfaces occurred to determine moisture content of test surfaces (Yaar 2016).
- Concrete test surfaces were cured for about 30 days prior to the start of Phase 2. All concrete surfaces used in this test had the same curing time.
- The following information and data needed for a qualitative evaluation of the experiment were acquired: (1) ancillary equipment required, (2) applicability of the decontamination technology to other contaminants and substrates, (3) estimation of capital and operating costs incurred (to be completed under separate cover), (4) deployment and operational data, (5) applicability to irregular surfaces, (6) skilled labor requirement, (7) utilities requirements, (8) extent of portability, (9) shelf life of media, (10) degree of damage to the surfaces, (11) waste management including estimated amounts and characteristics of spent media and rinse water, and (12) any health or safety concerns about use of the technology.

As shown in Appendix C, parameters tested in the November experiment were the vertical surface type (concrete, marble, or limestone) and the decontamination gel type (DeconGel^{TM}1120 or EAI Supergel).

The tests utilized two isolation chambers to establish controlled temperature, RH, and airflow conditions, and to prevent spread of radioactive contamination outside the test facility. The IsoArk

decontamination isolation chambers used in this test, depicted on Figures 2-1 and 2-11, were specially designed and manufactured by Beth-El Industries Ltd (Beth-El Group 2015) for this test.

The concrete and ceramic test surfaces, shown on Figure 2-12, were manufactured by Tamar Group (specifications are in Appendix B). A total of six surfaces, each 1.5 by 2 meters and 0.15 meter thick, were used in the experiments. The surfaces had been prepared about 2 months before the tests, and were allowed to equilibrate for 3 days under the controlled environmental conditions of the isolation chamber prior to contamination of these surfaces with the ^{86}Rb radionuclide solutions. All the surfaces were divided into 12 sub-sectional areas of 0.5 by 0.5 meter each that were preliminarily marked on the surface, as shown on Figure 2-12.

Figure 2-11. IsoArk decontamination isolation chambers

Figure 2-12. Concrete and limestone surfaces after division into 12 subsections of 0.5 by 0.5 meter each

All the surfaces were placed on a specially designed steel stand that allowed adjustment of the surfaces between horizontal and vertical positions. Surfaces were in the horizontal position during contamination of the surfaces with the ^{86}Rb solution and measurements of the contamination in all phases of the experiment. Surfaces were in the vertical position during application and removal of the decontamination materials, simulating possible building wall surfaces.

2.6 Radionuclides – Test Program 2

Radioactive ^{86}Rb chloride salt dissolved in water was purchased from a certified supplier abroad and used without further purification. Total source activity used in the experiment was 1 mCi of ^{86}Rb. The concentrated radioactive solution was divided by use of a micropipette and poured into common household spray bottles containing 300 mL of distilled water per bottle to prepare the final solutions that were used to contaminate the tested surfaces (a different bottle was prepared for every surface). Total activity used was about 167 µCi per surface. The radionuclide contaminants were applied to the test surfaces (two concrete, two marble, and two limestone) at staggered time intervals during the first day of the experiment, according to the experimental timetable presented in Appendix C.

2.7 Radiation Measurements – Test Program 2

Radiation measurements proceeded by use of the Rotem RAM-SURF portable contamination meter (Rotem 2015), shown on Figure 2-3; the Universal Detection Technology PDS-100G/ID personal

radiation detector, shown on Figure 2-4; and a collimated 2" NaI(Tl) scintillation PM-11 Detector, shown on Figures 2-5 and 2-13.

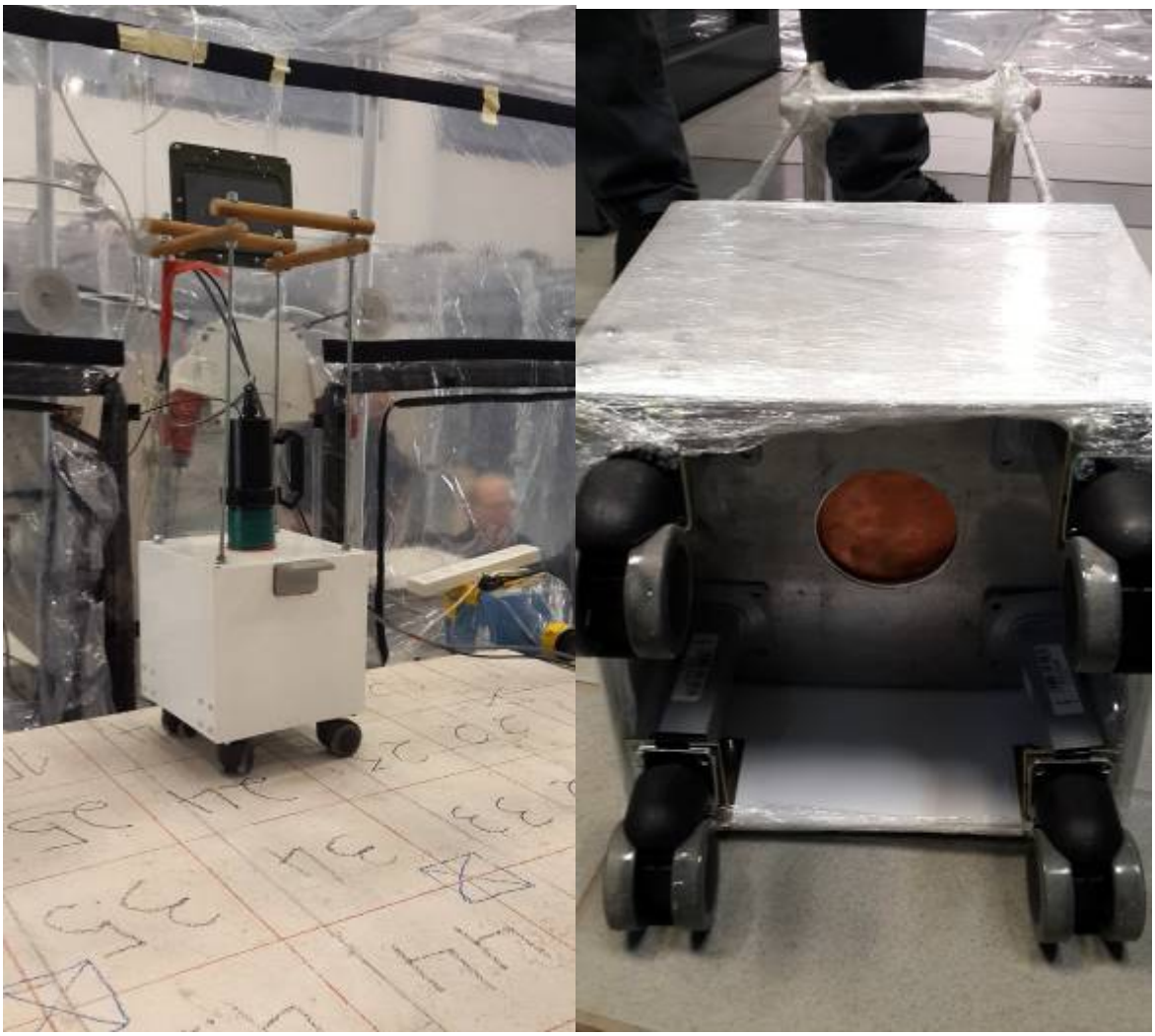


Figure 2-13. PM-11 2" NaI(Tl) scintillation lead-shielded detector

During surface measurements, the NaI(TI) detector was shielded with 40-mm-thick lead cylindrically wrapped around the detector. In addition to the lead shield, 1 mm of copper was placed in front of the detector to prevent beta and low-energy X-ray radiation from interfering with the gamma measurements. The lead shield was attached to a designated plastic box, shown on Figure 2-13, and the NaI(Tl) detector was placed inside the shield. The plastic box was fitted with wheels positioned at fixed height of 0.25 meter above the scanned area. During the surface measurement, the detector was moved to obtain a detailed map of the surface contamination, according to the divided 12 individual sub-surfaces measuring 0.5 by 0.5 meter that were preliminarily marked on the surfaces.

2.8 Decontamination Gels – Test Program 2

Two gels were used in these tests: DeconGel™ was used in one isolation chamber, and EAI Supergel was used in the other. Refer to Section 2.4 for complete descriptions of each product.

Drying time for the DeconGel™1120 was 48 hours. Removal of this product from the surfaces used in this test was difficult, and a sharp tool was needed. After removal, the dried sheets of DeconGel™ were packed and disposed of easily.

Figure 2-14. The torque-stirrer used to prepare the EAI Supergel

Contact time for the EAI Supergel was 30 min, and the gel was removed by use of an industrial vacuum cleaner, shown on Figure 2-15. A change in contact time was made following Round 1 where a contact time of 90 minutes resulted in gel that had dried on the surface and was difficult to remove. Removal of the EAI Supergel was easier than removal of the DeconGel™1120.

Figure 2-15. The industrial vacuum cleaner used to remove the EAI Supergel

Both gels were applied by use of a hand-held power sprayer with a wide shot tip number 531, shown on Figure 2-16. Refer to Section 2.4 for a complete description of the sprayer application.

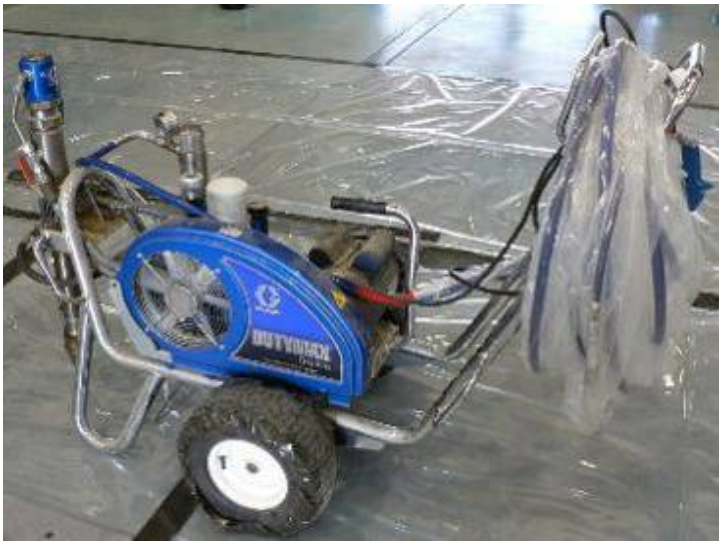


Figure 2-16. The sprayer used to apply the decontamination gel to the surface

3.0 Results

3.1 Test Program 1

Results discussed in this section were obtained during the ^{86}Rb test at the Ramla site (January 11-21, 2015) and during the ^{137}Cs test at NRCN (March 1-12, 2015).
A preliminary test occurred during January 4-8, 2015, a week before the ^{86}Rb test, by use of the short half-life radioisotope ^{99m}Tc. This part of the experiment was conducted to estimate the applicability of the decontamination technology, not to calculate decontamination factors (percent removal). Nonetheless, some results obtained during the preliminary ^{99m}Tc test are listed in Appendix D.

Setup of the surfaces and parameters tested at the Ramla site during the ^{86}Rb set of experiments is indicated below in Table 3-1. As evident in Table 3-1, every surface was marked with a two-digit number. The first digit is the tent number, 1 for the tent where DeconGel™ was used and 2 for the tent where EAI Supergel was used. The second digit is the position of the surface inside the isolation tent—1 is the surface positioned at the back of the tent, 2 is the surface positioned at the middle of the tent, and 3 is the surface positioned at the front of the tent close to the entrance.

Tested parameters were:

- Decontamination gel type: DeconGel™ or EAI Supergel
- Surface type: concrete or ceramics
- Time before applying the gel: 48 or 96 hours, following application of the isotope.

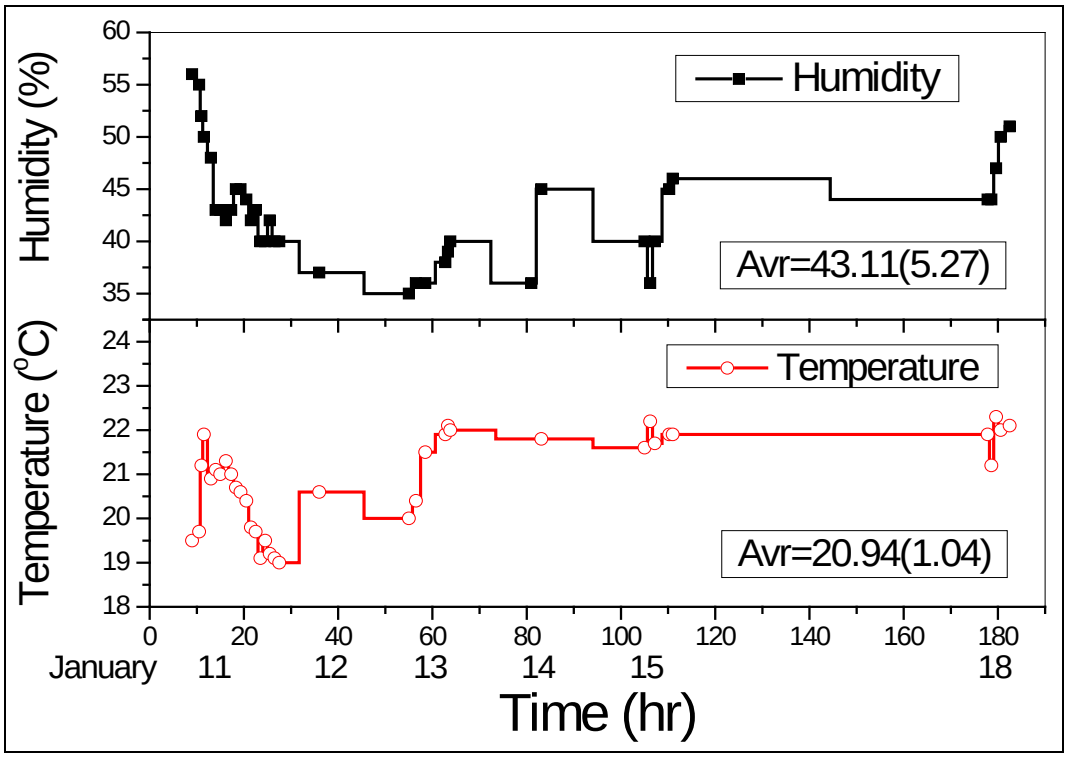
Table 3-1. Setup of surfaces inside the chambers and parameters tested at the Ramla site during the ^{86}Rb set of experiments (January 11-21, 2015))

Isolation Chamber/ Gel Type	Surface		
1 / DeconGelTM	11 Concrete 48 hrs	12 Ceramics 48 hrs	13 Ceramics 96 hrs
2 / EAI Supergel	21 Concrete 48 hrs	22 Ceramics 48 hrs	23 Concrete 96 hrs

Humidity and temperature at the Ramla site were controlled by use of a central air-conditioning system. However, on certain days, because of fast climate changes during the first 2 weeks of January, the air-conditioning system could not maintain constant humidity and temperature conditions, as shown on Figure 3-1.

Average values of 20.94 ± 1.04 degrees Celsius (°C) and 43.11 ± 5.27% (± values are standard deviations) were calculated for temperature and humidity, respectively, during the experiment

time. Results conveyed here were measured at the room close to the isolation chambers; readings taken inside the chambers from time to time were similar to those.



Avr = Average

Figure 3-1. Humidity and temperature at the Ramla site (January 11-18, 2015)

The experimental procedure applied at every surface included nine steps: (1) background measurements; (2) surface contamination with 300 mL of ^{86}Rb solution with an activity of 16.7 µCi per surface; (3) ^{86}Rb contamination level measurements; (4) application of the first gel layer (48 or 96 hours after contamination), about 6 L of gel per surface; (5) decontamination process; (6) ^{86}Rb contamination level measurements after the first decontamination process; (7) application of the second gel layer;(8) decontamination process; and (9) ^{86}Rb cumulative (first plus second) contamination level measurements after the second decontamination process.

Depicted in Appendix E are measurement results of steps (1) background, (3) ^{86}Rb contamination level, (6) ^{86}Rb contamination level after the first decontamination process, and (9) ^{86}Rb value cumulative contamination level after the second decontamination process.

Calculated percent removals (%R) after the first and second decontamination processes are also depicted in Appendix E, and on Figures E-2 (surface 12, DeconGel™) and E-4 (surface 21, EAI Supergel).

All measurements appearing on the figures were taken by use of the NaI(Tl) 2" detector. Only two surface measurement results obtained in these experiments are plotted in this report because average percent removal values were calculated from the raw data files and not from these plots. Plotting more of the same results would not convey to the reader more usable information about the cleaning process.

Results of the ^{137}Cs test at NRCN are depicted in Appendix E, on Figures E-5 to E-12 for each set of tested parameters: surface type (concrete or ceramics) and gel type (DeconGel™ or EAI Supergel). Measurement results of steps (3) contamination level, (6) contamination level after the first decontamination process, and (9) contamination level after the second decontamination process are first depicted for all of the four surface-gel combinations. Calculated %Rs after the first and second decontamination processes are also depicted. All measurements were taken by use of the NaI(Tl) 2" detector.

Data acquired from every surface at the Ramla site by use of ^{86}Rb and from surfaces at NRCN by use of ^{137}Cs were corrected according to the radioactive decay of the tested isotope (this correction was needed only for ^{86}Rb), and were analyzed after reduction of background radiation. To improve the statistics of counting, the spectra of every four adjacent 0.25 by 0.25 meter measuring points were integrated into one 0.5 by 0.5 meter result. Overall, 12 measuring points were obtained for every surface in each step (background, radioisotope contamination level, radioisotope contamination level after the first decontamination process, and radioisotope contamination level after the second decontamination process). Average %Rs and their standard deviations after the first and second decontamination processes, calculated for every surface from these results, are listed in Table 3-2. The %Rs were calculated by application of the same methodology used in the past by EPA (Drake 2011a):

$$\%R = (1-A_f/A_i) \times 100\%$$

Where A_i (initial activity) and A_f (final activity) are average radiological activities of the surfaces before and after the decontamination process, respectively, as recorded by the 2" NaI(Tl) gamma detector.

Table 3-2. Average percent removal (%R) values and standard deviations after the first and second decontamination processes, as calculated for every surface (%Rs calculated after the second process are cumulative values calculated from both first and second process)

Surface	Gel type	Isotope	48 hours*		96 hours	
			First Layer	Second Layer	First Layer	Second Layer
Concrete	DeconGel™	^{86}Rb	24.1 (±4.2)	27.1 (±3.9)	---	---
		^{137}Cs	26.5 (±3.7)	33.9 (±4.6)	---	---
	EAI Supergel	^{86}Rb	32.3 (±5.9)	44.4 (±7.6)	36.3 (±9.3)	59.9 (±12.9)
		^{137}Cs	30.1 (±4.6)	45.8 (±3.7)	---	---
Ceramics	DeconGel™	^{86}Rb	65.5 (±8.0)	89.9 (±6.0)	82.2 (±4.7)	---
		^{137}Cs	63.5 (±8.3)	80.0 (±3.9)	---	---
	EAI Supergel	^{86}Rb	81.9 (±5.6)	92.0 (±2.3)	---	---
		^{137}Cs	78.1 (±3.9)	86.1 (±3.6)	---	---

* Each difference in a pair of results (associated with a particular gel type coated on a particular surface) considered statistically insignificant is marked with yellow background, and each difference in a pair of those results considered statistically significant is marked with green background. For example, the difference in the pair of average %Rs obtained from concrete coated with DeconGel™ (first layer) is statistically insignificant (yellow), while the difference in average %Rs obtained from concrete coated with DeconGel™ (second layer) is statistically significant (green). Each result in a pair of results derived from use of a specific radioisotope as the source of radiation (^{86}Rb or ^{137}Cs).

In gamma measurements by use of the 2" NaI(Tl) gamma detector, the detector field of view, and therefore the measurement special resolution, was limited to an integration over an area of 0.25 by 0.25 meter, with no ability to determine the distribution of contamination inside of the area. In an attempt to obtain a more detailed contamination distribution map, some image-plates were positioned at several areas on the contaminated surfaces. The image-plates (Lee and others 2000) were placed after the first decontamination cycle and were left over the weekend to accumulate the signal. These plates were taken to NRCN for development.

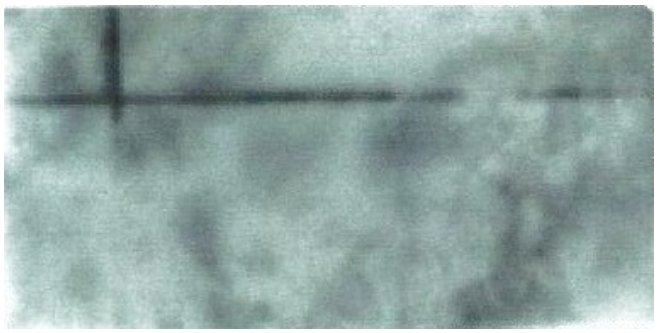


Figure 3-2. An image-plate picture taken from one of the ceramics surfaces cleaned by the EAI Supergel, after the first decontamination cycle

One image taken from one of the ceramics surfaces cleaned by the EAI Supergel is shown on Figure 3-2. Dark lines indicate areas of higher radiation levels. These areas, left after cleaning off the EIA Supergel by use of an industrial vacuum cleaner, are where mortar was located between the ceramic tiles, where most of the remaining contamination was concentrated, leaving the tile surface almost contaminant-free. The other pictures taken by the image-plates, not shown here, showed similar results. Therefore, this test was not repeated in Phase 2 of the experiment.

Some pictures taken at the Ramla site during gel application and removal processes appear on Figure 3-3 and Figure 3-4, respectively.

Figure 3-3. Pictures taken during the gel application process (DeconGel™ on the left and EAI Supergel on the right)

Figure 3-4. Pictures taken during the gel removal process (DeconGel™ on the left and EAI Supergel on the right)

In addition to the calculated decontamination efficiency values, listed in Table 3-2, some of the decontamination operational parameters (e.g., time, man power, gel volume, waste volume) , were also measured during the test. Some estimated values of operational aspects of the decontamination process, calculated from the ^{86}Rb test at Ramla, are listed in Table 3-3.

Table 3-3. Operational factors gathered during the Ramla 86Rb test, average values and standard deviation in parentheses

Parameter		Concrete	Ceramics
Application time (min/m^2)	**DeconGel™**	3.2 (±0.2)	2.0 (±0.6)
	EAI Supergel	4.1 (±1.2)	
Total dwell time (hr)	**DeconGel™**	Minimum of 24-48 for draying (depending on environmental conditions and surface type)	
	EAI Supergel	maximum of 1.5 before removing	
Removal time (min/m^2)	**DeconGel™**	2.5 (±0.2)	1.2 (±0.5)
	EAI Supergel	5.4 (±1.5)	
Gel Volume (liter/m^2)		2.7 (±1)	2.0 (±1)
Waste volume (cm^3/m^2)*	**DeconGel™**	1440 (±38)**	1058 (±18)

Notes:

* cm^3 of waste per m^2 of surface area treated with the DeconGel™. Results for the EAI Supergel were not recorded because this liquid-like gel was transferred directly from the vacuum cleaner into a Vermiculite cask.

** Concrete waste volume was 36% larger than ceramic waste volume because more gel was used on the concrete surfaces to ease the stripping process from those surfaces.

cm Centimeter
hr Hour
m Meter
min Minute

In addition to the quantifiable operational parameters listed in Table 3-3, some qualitative evaluation aspects about the work conducted are as follows:

- DeconGel™ proved less suitable for decontamination of textured surfaces such as concrete, asphalt, or limestone than the EAI Supergel.
- EAI Supergel dried rapidly. Therefore, this gel should be vacuumed no more than 30 min after spraying it onto the surface. Manufacturer instructions and results obtained by us in the second test indicate that the shorter time does not significantly influence efficiency of gel decontamination.
- Preparation of both gels for use is not complicated, with an advantage to the DeconGel™ as a ready-to-use commercial product. Time needed to prepare the EAI Supergel on site was less than 20 min for 10 L of the gel. This time can be reduced depending on size of equipment used.

- Because of safety regulations, only experienced and authorized decontamination personnel participated in the test. However, in a real situation, construction laborers or tradesmen could conduct decontamination after undergoing a short training.
- Both materials are not toxic and are easy to use.
- DeconGel™ might damage irregular and porous surfaces somewhat, while EAI Supergel will not. This damage is evidenced by small concrete fragments turned out from the surface of the concrete during the stripping process (this can be further examined in the future via an experiment without use of radioactive materials).
- The same instrumentation is needed to apply both materials. Removal of DeconGel™ can proceed mostly by use of hand tools, while an industrial vacuum cleaner is necessary to remove EAI Supergel.

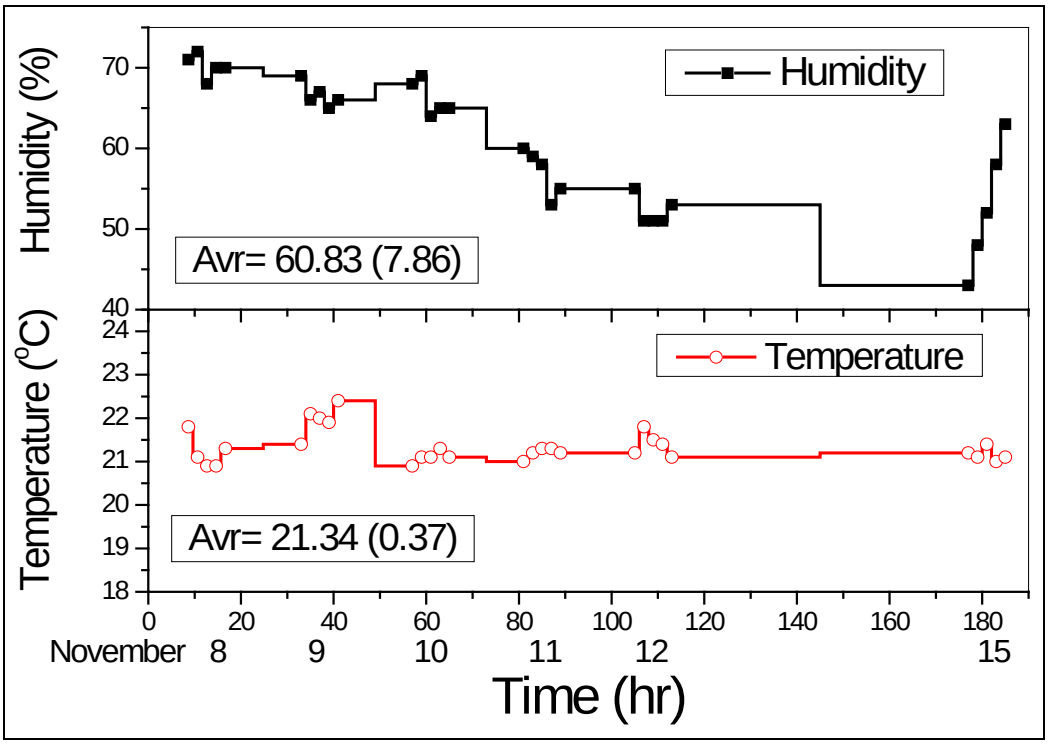
3.2 Test Program 2

Results presented in this section were obtained during the ^{86}Rb test at Ramla (November 8-15, 2015). Setup of surfaces and parameters tested are listed in Table 3-4. The test parameters listed in Table 3-4 are Decontamination gel type (DeconGel™ or Argonne Super Gel), and the surface type (concrete, marble, or limestone). The first digit is the tent number—1 for the tent where DeconGel™ was used and 2 for the tent where EAI Supergel was used. The second digit is the position of the surface inside the isolation tent—1 for the surface positioned at the back of the tent, 2 for the surface positioned in the middle of the tent, and 3 for the surface positioned at the front of the tent close to the entrance.

Table 3-4. Setup of surfaces inside the isolation chambers and parameters tested at Ramla during the ^{86}Rb set of experiments (November 8-15, 2015)

Isolation Chamber / Gel type	Surface number / Type		
1 / DeconGel™	11 / Concrete	12 / Marble	13 / Limestone
2 / EAI Supergel	21 / Concrete	22 / Marble	23 / Limestone

Humidity and temperature at the Ramla site were controlled by use of a central air-conditioning system. Measured values for both parameters are shown on Figure 3-5. Average values of 21.34 ±0.37°C and 60.83 ±7.86% (± values are standard deviations) were calculated for temperature and humidity, respectively, during the experiment time. Results presented here were obtained at the center of the experimental hall, close to isolation chambers; readings taken inside the isolation chambers from time to time indicated similar results.



Avr = Average

Figure 3-5. Humidity and temperature at the Ramla site (November 8-15, 2015)

The experimental procedure for every surface according to the experimental test plan included nine steps: (1) background measurements, (2) surface contamination with 300 mL of ^{86}Rb solution, (3) ^{86}Rb contamination level measurements, (4) application of the first gel layer containing about 6 L of gel per surface, (5) first decontamination process, (6) ^{86}Rb contamination level measurements after the first decontamination process, (7) application of the second gel layer, (8) second decontamination process, and (9) ^{86}Rb contamination level measurements after the second decontamination process.

Measurement results from every surface at the Ramla site were corrected according to the radioactive decay of ^{86}Rb and analyzed after reduction of background radiation. Overall, 12 measuring points were obtained for every surface in each step (background, ^{86}Rb initial contamination level, ^{86}Rb contamination level after the first decontamination process, and ^{86}Rb contamination level after the second decontamination process) for each one of the three detectors used (2" NaI(Tl), PDS-100G/ID, and RAM-SURF). Average %Rs were calculated by application of the same methodology described in Section 3.1.

Measurement results of steps 3, 6, and 9, as well as calculated %Rs after the first and second decontamination processes, with NaI(Tl) 2" as the detector, are depicted in Appendix F on Figures F-1 to F-6. Average %Rs after the first and second decontamination processes, with PDS-100G/ID and RAM-SURF as the detectors, are depicted in Appendix F on Figures F-7 to F-12.

Average %Rs and standard deviations after the first and second decontamination processes, as calculated for every surface and detector via the equation shown in Section 3.1, are listed in Table 3-5.

Regarding the gamma measurements by the 2" NaI(Tl) gamma detector, the detector field of view (and therefore measurement special resolution) was limited to an integration over an area of 0.5 by 0.5 meter. PDS-100G/ID and the RAM-SURF beta/gamma radiations were measured without collimation.

Table 3-5. Average %Rs and standard deviations (in parentheses) after the first and second decontamination processes, as calculated for every surface, gel, and detector type

Surface	Gel	First decontamination process			Second decontamination process		
		NaI(Tl)	PDS-100G/ID	RAM-SURF	NaI(Tl)	PDS-100G/ID	RAM-SURF
Concrete (1)	DeconGel™	8.8 (±4.0)	20.5 (±3.8)	23.9 (±6.6)	13.6 (±3.7)	21.5 (±1.2)	35.0 (±7.7)
	EAI Supergel	32.5 (±8.1)	29.1 (±10.7)	59.9 (±9.5)	42.7 (±7.7)	37.3 (±15.3)	74.5 (±6.1)
Marble (2)	DeconGel™	17.1 (±5.1)	12.3 (±7.2)	36.2 (±18.2)	28.1 (±3.4)	29.6 (±10.0)	55.2 (±9.9)
	EAI Supergel	31.4 (±5.0)	24.4 (±9.6)	42.2 (±7.9)	38.4 (±4.5)	35.3 (±12.5)	67.8 (±3.2)
Limestone (3)	DeconGel™	39.0 (±6.4)	22.1(±12.2)	36.6 (±9.4)	45.2 (±4.4)	36.1 (±8.9)	50.0 (±14.4)
	EAI Supergel	26.4 (±3.7)	28.6 (±11.3)	54.4 (±11.3)	35.2 (±4.9)	34.1 (±7.8)	71.9 (±5.3)

Several important conclusions can be deduced from the results listed in Table 3-5:

- In 15 out of 18 cases, average %R with use of EAI Supergel was larger than that with use of DeconGel™ by about 17%.
- Cumulative, calculated, average %Rs after the second cleaning process exceeded %Rs measured after the first cleaning process by averages of about 9% (gamma measurements) and 17% (beta measurements).
- Average %R calculated from all beta measurements by the RAM-SURF meter was larger by about 18% and 26% after the first and second cleaning processes, respectively, than

the average %R calculated from all gamma measurements by the 2" NaI(Tl) and PDS-100G/ID detectors.

Some pictures taken at the Ramla site during the gel application and removal processes are depicted on Figure 3-6 and Figure 3-7, respectively.

Figure 3-6. Gel application process (DeconGel™ top and EAI Supergel bottom)

Figure 3-7. Gel removal process (DeconGel™ left and EAI Supergel right)

In addition to the average %Rs listed in Table 3-6, operational factors gathered during the decontamination processes are listed in Table 3.

Table 3-6. Average values of operational factors gathered during the Ramla ^{86}Rb test (standard deviation values are in parentheses)

Parameter		Concrete	Marble	Limestone	Average
Application time (1st, 2nd) (min/m²)	DeconGel™	2 , 4	2.7 , 4.3	3.7 , 5	**3.6 (±1.1)**
	EAI Supergel	1.7 , 1	2 , 4	1 , 5.3	**2.5 (±1.8)**
Delay time needed before removal (hr)	DeconGel™	**48**			
	EAI Supergel	**0.5**			
Removal time(1st, 2nd) (min/m²)	DeconGel™	43*, 4	6.3 , 6	3 , 5.7	**5.0 (±1.4)**
	EAI Supergel	8.3 , 5	5 , 6	5.3 , 3.3	**4.9 (±1.0)**
Gel Volume (liter/m²)	Both gels	**2-2.5**			
Waste volume (cm³/m²)	EAI Supergel	**2-2.5** (in the wet phase)			

Notes:

* The time period of the first removal by DeconGelTM from surface 1.1 (concrete), marked in red, was much longer (129 min) than all the other measured time values, and was therefore omitted from calculation of average removal time.

cm	Centimeter
hr	Hour
m	Meter
min	Minute

In addition to the quantifiable parameters listed in Table 3-6, some qualitative evaluation aspects about the work conducted are as follows:

- DeconGel™ is less suitable for decontamination of textured surfaces like concrete, asphalt, or limestone.
- EAI Supergel dries rapidly. Therefore, this gel should be vacuumed no more than 30 min after spraying it on the surface (this time is influenced by temperature and relative humidity on site).
- Preparation of both gels for use is not complicated, with an advantage to DeconGel™ that comes as a ready-to-use commercial product. Time needed to prepare EAI Supergel on site was about 20 min for 10 L. This time can be reduced by use of large industrial mixing equipment.
- Because of safety regulations, only skilled and authorized decontamination personnel participated in the test. However, in a real situation, unskilled workers could conduct the decontamination after undergoing a short training.
- Both materials are not toxic and are easy to use.
- DeconGelTM might damage irregular and porous surfaces somewhat. This damage is evidenced by small concrete fragments turned out from the surface of the concrete during the stripping process (this can be further investigated in the future via an experiment without use of radioactive materials).

4.0 Data Quality Assurance

4.1 Test Program 1

The contamination measurement process initially proceeded as planned, by use of all three detectors (RAM-SURF, PDS-100G/ID, and 2" NaI(Tl)) taking 48 data points (0.25 by 0.25 meter for every measuring point) from every surface. However, due to the low readings recorded, especially after the first and second decontamination cycles, only the 2" NaI(Tl) detector readings were found statistically valid. To strengthen the statistical precision of these measurements, every four adjacent measurement point readings were integrated into one point representing an area of 0.5 by 0.5 meters, and resulting in 12 measurement points per surface, with better statistics for every measurement point.

Preliminary calibration of the 2" NaI(Tl) detector, prior to measurements of radiation from ^{86}Rb and ^{137}Cs, proceeded by use of a low-activity ^{60}Co source. Following that calibration process, performed outside the isolation chamber, the detector was calibrated inside the chamber by use of ^{86}Rb and ^{137}Cs with references to the ^{86}Rb 1076.64 keV and ^{137}Cs 661.7 keV peaks. A sample of the stability of this calibration process for the 2" NaI(Tl) detector by reference to the characteristic peak of radioisotope ^{86}Rb at 1076.64 keV is depicted on Figure 4-1 and Figure 4-2.

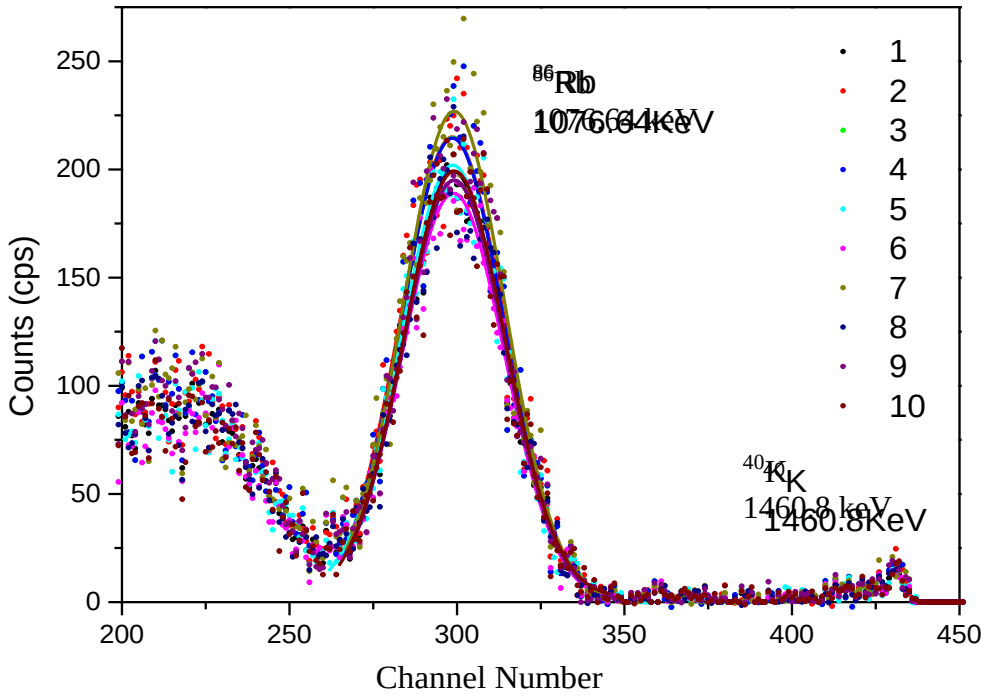


Figure 4-1. Ten calibration spectra generated by the 2" NaI(Tl) detector by use of radioisotope ^{86}Rb—obtained inside the isolation chamber

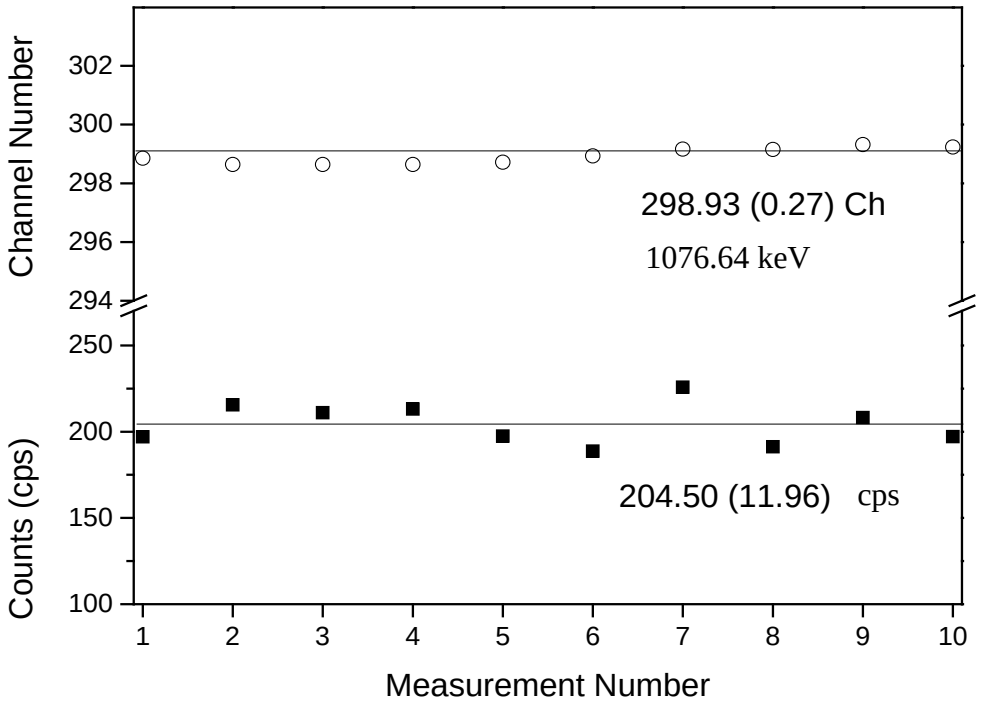


Figure 4-2. Results of the calibration process based on the 10 ^{86}Rb spectra depicted on Figure 4-1

Results of average %Rs listed in Table 3-5 were tested by application of the statistical unpaired t-test model, with N=12 and 95% confidence interval of difference for every pair of results, in order to calculate whether differences in average %Rs resulting from use of ^{86}Rb and ^{137}Cs as sources of radiation were significant or not. Results of these tests are listed in Table 3-2, where differences considered insignificant are marked with yellow background, and differences considered significant are marked with green background.

As evident in Table 3-2, results of the statistical t-test were inconclusive. Three of the pairs were found statistically different, and five were not found significantly different. Overall average calculated difference value between the decontamination factors of both isotopes, based on all the pairs, was -0.8 (±11.8%), regardless of the decontamination gel or surface type. Therefore, it was concluded that this experiment indicated no statistically significant difference between results based on use of ^{86}Rb and results based on use of ^{137}Cs. This finding was similar to findings of an experiment at NRCN in an earlier phase of this program, whereby Rb was tested in a lab setting to determine if it could serve as a surrogate for Cs in a decontamination setting (Paz and others 2014). Thus, ^{86}Rb can be considered a good surrogate for ^{137}Cs for the types of materials tested here.

4.2 Test Program 2

The contamination measurement process proceeded as planned, with use of all three detectors (RAM-SURF, PDS-100G/ID, and 2" NaI(Tl)), and 12 measuring points (0.5 by 0.5 meter for every measuring point) from every surface.

As shown on Figure 3-5, preliminary calibration of the 2" NaI(Tl) detector (before its involvement with ^{86}Rb measurements) occurred by use of a low-activity ^{60}Co source. After that preliminary calibration (performed outside the isolation chamber), the detector was calibrated inside the chamber with use of ^{86}Rb and reference to the ^{86}Rb 1076.64 keV peak.

Average and standard deviation values listed in Tables 3-5 and 3-6 were calculated by use of regular normal statistical distribution functions. About 6% outliers results found to be more than 4σ away from the calculated average value were omitted from the calculations. Explanation for this large deviation was not apparent. However, several possible causes include wrong position of the detector while taking the measurement, a mistake in the manes of one of the files (background, first, or second measurement), or resuspension of the contamination from one mastered area of 0.5 by 0.5 meter to a neighbor area during the cleaning process.

5.0 Summary of Results and Discussion

Results obtained during both tests are presented in this report. The tests occurred in Israel with use of large surfaces (1.5 by 2 meters) made of concrete, ceramic, marble, and limestone; two types of decontamination gels (DeconGel™ and Argonne Super Gel); two types of radionuclides (^{86}Rb and ^{137}Cs); and two different time periods before application of the gel on the contaminated surface (48 hours and 96 hours).

Previous EPA experimental results (Drake 2011a, b; 2013b, e) from work with comparable decontamination gels yielded %Rs of 67 ± 9%, 35 ± 13%, and 93 ± 0.9% for DeconGel™ 1108 application on concrete, limestone, and marble, respectively; and 73 ± 5%, 16 ± 6.3%, and 71 ±4% for EAI Supergel application on concrete, limestone, and marble, respectively.

5.1 Test Program 1

From these results, %Rs and some operational parameters were determined for the decontamination process involving the two radionuclides. This section summarizes these results and the major conclusions drawn from them, and compares the results to those obtained from previous EPA experiments with similar decontamination gels on small coupons of 0.15 by 0.15 meter.

Final %R values for the different surfaces and decontamination gels calculated after the second decontamination process are listed in Table 5-1. As stated in Sections 3 and 4 of this report, no significant difference was found between %Rs resulting from use of the two radionuclides (^{86}Rb and ^{137}Cs) or between the wait times before application of the decontamination gel to the surface (48 or 96 hours). Two major conclusions can be drawn from the results listed in Table 5-1: first, decontamination efficiency of EAI Supergel is higher than that of DeconGel™ by about 10%; second, overall efficiency of decontamination of ceramic surfaces is about twice overall efficiency of decontamination of concrete surfaces.

Table 5-1. Average calculated %Rs for the different surfaces and decontamination gels (standard deviations in parentheses). Results are averages from uses of both ^{86}Rb and ^{137}Cs

Decontamination Gel	Gel application	Concrete (%R)	Ceramic (%R)
DeconGel™	**First**	25 (±3)	70 (±4)
	Second*	31 (±3)	85 (±4)
Argonne Super Gel	**First**	33 (±4)	80 (±3)
	Second*	50 ± (3)	89 (±2)

* Accumulated average calculated %Rs from both decontamination processes

Results calculated in this experiment, listed in Table 5-1, were not significantly different from EPA's previously reported results for concrete and marble (assuming that marble and ceramics have similar %Rs).

Most operational factors documented during the decontamination process using ^{86}Rb at Ramla (see Section 3 and Table 3-3) cannot be compared to the parameters documented during earlier EPA research studies (Drake 2011a, b; 2013b, e). In earlier EPA experiments, gel application to the small concrete coupons occurred by use of 4-inch paint brushes. This process was relatively slow and took approximately 25 min/m^2 and 40 min/m^2 for application and removal, respectively, of one coat of DeconGel™ 1108 on the concrete coupons; and 60 min/m^2 for application and removal of one coat of EAI Supergel on the same coupons. DeconGel™ 1108 comes as a ready-to-use compound, while the EAI Supergel requires a preparation time of 15 min for mixing the powders with water. Application and removal times listed here were calculated based on results presented in the EPA references listed above.

Comparable application times measured in large-scale (1.5 by 2 meter) tests described in this report were 3.2 (0.2) min/m^2 (number in parentheses is standard deviation) and 2 (0.6) min/m^2 for the comparable one coat of DeconGel™ 1120 on concrete and ceramics, respectively; and 4.1 (1.2) min/m^2 for one coat of EAI Supergel on both surfaces (concrete and ceramics). Application was by use of a professional paint sprayer, depicted on Figures 2-10 and 2-16. Time needed for mixing the EAI Supergel powders with water was approximately the same (10-15 min). Setup time for the paint sprayer system was about 15 min, and two skilled workers were needed for its operation. However, total spraying time with this system was about an order of magnitude lower than the time needed for a worker using the paint brush in the earlier EPA tests. This system is suitable for small-to-medium size contaminated surfaces or rooms. A more robust and self-mobile system would be necessary to decontaminate larger areas, and time required to apply the material this way would probably be shorter.

Times periods for removals of gels used in this experiment were 2.5 (0.2) min/m^2 (number in parentheses is standard deviation) and 1.2 (0.5) min/m^2 for the DeconGel™ on concrete and ceramics, respectively; and 5.4 (1.5) min/m^2 for EAI Supergel on both surfaces. Time needed to remove the DeconGel™ from the concrete surface was twice the time needed to remove it from the ceramics surface because of stronger attachment of the gel to the rough texture of the concrete surface. Again, comparing EPA's small-scale experiment to our large-scale experiment is not straightforward. Removal of DeconGel™ from the surface occurred via a simple stripping process, almost regardless of surface size. Removal of EAI Supergel occurred by use of an industrial vacuum cleaner that was not optimized for this process; some modifications to the sucking head occurred during the experiment to facilitate the cleaning process. A second factor in EAI Supergel removal time was the too-long, 90-min wait period before gel removal, affecting its viscosity and causing it to stick to the surface (especially to the concrete). Shorter waiting time of about 30 min before removal of this gel from the surface is recommended in future experiments.

Volumes of dry DeconGel™ 1120 sheets after removal from the concrete and ceramic surfaces were 1440 (38) cm^3/m^2 and 1058 cm^3/m^2 (cm^3 of waste per m^2 of surface area treated with DeconGel™), respectively. The comparable volume measured by EPA for DeconGel™ 1108 removed from concrete coupons was 252 cm^3/m^2. However, viscosity of new DeconGel™ 1120 gel seems to be much lower than that of DeconGel™ 1108 gel, and therefore thicker layer of gel was needed to render it peelable from the concrete surface, resulting in a volumetric increase in waste. Volume of EAI Supergel generated during the surface decontamination process was not measured in this experiment, and the material was fixed in vermiculite at the end of every process. A real cleaning process will require a separate process of drying this gel in a dedicated furnace to decrease its volume and avoid dealing with a wet radioactive substance.

The overall qualitative evaluation is that DeconGel™ is suitable for decontamination of smooth and small surfaces, such as those inside radioactive laboratories or facilities, whereas EAI Supergel can be used easily on any surface, including textured surfaces such as concrete, asphalt, or limestone. Because use of a vacuum cleaner is necessary to remove EAI Supergel, whereas removal of DeconGel™ can occur by hand, less overall time is required for the decontamination process by use of DeconGel™ on medium-size surfaces (like the surfaces used in this test). However, this situation may change if cleanup of a large contaminated area outside occurs by use of an industrial vacuum cleaner instead of hand-held vacuum equipment.

In this research, conducted in November 2015, the same procedures were tested on vertical surfaces, with small changes introduced that accorded with lessons learned from this work and from EPA tests during June 2015 in Columbus, Ohio.

5.2 Test Program 2

Test Program 2 resulted in determinations of average %Rs and conclusions regarding some operational parameters of the decontamination process. This section summarizes these results and major conclusions drawn from them, and compares the results to those from Test Program 1 experiments on horizontal surfaces.

Major conclusions drawn from the summary of experimental results listed in Tables 3-5 and 3-6 are:

- Overall average (%R) for EAI Supergel is larger than that for DeconGel™.
- The second cleaning process improves overall cleaning efficiency.
- Average %Rs calculated from beta measurements are larger than those calculated from gamma measurements.
- DeconGel™ is not suitable for decontamination of textured surfaces, but works well on smooth, non-porous surfaces.
- EAI Supergel should be vacuumed no more than 30 min after spraying it on the surface.

- Processes of preparing both gels for use are not complicated, with an advantage to DeconGel™ that comes as a ready-to-use commercial product.
- Unskilled workers can be used to conduct decontamination after undergoing a short training.
- Both materials are not toxic, easy to use, and easily set up.
- Use of both materials generated very low amounts of dry waste materials.
- DeconGel™ might damage irregular and porous surfaces somewhat.

In previous experiments, horizontal surfaces made of concrete and ceramic contaminated with two radioisotopes ^{86}Rb and ^{137}Cs were decontaminated by use of EAI Supergel and DeconGel™. Results of these experiments induced similar conclusions regarding time needed to clean the surfaces, better decontamination results from use of EAI Supergel than from use of DeconGel™, inappropriateness of DeconGel™ to clean irregular and porous surfaces, and improvement in the decontamination factor after repeating the decontamination process. Comparing cleanups of horizontal and vertical surfaces, no significant differences were found in calculated average %R for concrete (the only surface used in both experiments) and in most operational parameters. The only significant differences found were:

- Time needed to spray EAI Supergel on a vertical surface was shorter (2.5±1.8 and 4.1±1.2 min/m^2 for vertical and horizontal surfaces, respectively).
- Time needed to remove DeconGel™ from the concrete vertical surface was longer (5.0±1.4 and 2.5±0.2 min/m^2 for vertical and horizontal surfaces, respectively).

Another parameter evaluated in this experiment for the first time was average %R calculated from both beta and the gamma measurements. This type of data evaluation allows us to differentiate between contamination on the surface, from where most of readings of beta radiation will come, and contamination that penetrates into deeper layers of the surface, where most beta radiation will be absorbed and from where only gamma radiation will be measured. Comprehensive measurements of the relative fraction of beta radiation absorbed in the surface material did not occur during this field experiment. These kind of measurements, complemented by simulations, can occur in the future in a small-scale laboratory experiment.

As expected, for all surfaces, average %Rs calculated by use of beta readings were higher than those calculated from gamma readings. This indicates that ability of both gels to clean upper layers of surfaces is better than their ability to penetrate surfaces and clean up contamination that penetrates the surfaces. Assumedly, percentage removed would be greater if the same test would be conducted with use of an alpha emitter, because of the smaller mean free path of this "radiation" (alpha particles [$helium^{+2}$]) in matter.

These findings indicate that in a real scenario, most radioisotopes that lie on the surface will be removed by the gel, leaving only those that penetrated the surface to a depth where they cannot

directly contaminate the environment or threaten recontamination that might result from actions of wind, rain, people, or passing vehicles; and these radioisotopes at depth can be addressed in later stages of the decontamination process.

Further experiments, in which samples from surfaces contaminated with alpha and beta emitters will be collected and measured as a function of depth, are necessary to verify this assumption.

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Appendix A: Isolation Chamber Specifications

IsoArk 220-520 decontamination chambers (isolation chambers) will be used for this project. The chambers are manufactured by Beth-El Zikhron Yaaqov Industries Ltd (Beth El Industries) in Zikhron Yaagov, Israel. The IsoArk is a portable, negative-pressure isolation chamber designed for patient treatment and biological, chemical, or radiological contamination sample handling; the decontamination chamber is used in hospitals, airports, and field hospitals. IsoArk is a complete solution for converting any room or space into a radiologically-contained area, allowing for isolation of contaminated people or samples. The IsoArk system meets all of today's standards for airborne-contaminated isolation, including Centers for Disease Control and Prevention (CDC) guidelines for healthcare infection control.

The airlock, attached to the main chamber, provides the capability of easy movement in and out of IsoArk without losing negative pressure or contaminating the outside environment.

IsoArk FA 2000 HSZ is a filtration system, equipped with a high-efficient particulate air (HEPA) filter and a radiation source. The HEPA filter traps airborne particulates, aerosols, and viruses, whereupon the radiation source destroys them. IsoArk FA 2000 HSZ is a self-contained mobile unit with three airflow modes, allowing quick air flushing or energy saving at low airflow mode. The IsoArk chambers that will be used in the test plan were preliminarily designed and manufactured according to NRCN special demands to meet all of the demands of this unique test plan. In particular, use of large surfaces, liquid radioisotope solutions, and several types of decontamination gels was considered.

Some typical operational parameters of the IsoArk system, as measured during a real field experiment, are listed in Table A-1, below. Figure A-1 that follows shows a front view of the IsoArk 220-520 Isolation Chamber and Filtration System. Figure A-2 thereafter shows a top view of the IsoArk 220-520 Isolation Chamber and Filtration System.

Table A-1: Typical Operational Parameters of the IsoArk System

Parameter	Chamber Empty			Chamber Operational		
	Minimum Level	Maximum Level	Maximum Delta	Minimum Level	Maximum Level	Maximum Delta
Temperature	23.2	24.2	1	23.2	24.2	1
Humidity (%)	52	52	-	52	55	3
Noise dB)	57	62		57	65	7
Pressure Pa)	-10 Pa	-15 Pa	-15 Pa	-10 Pa	-15 Pa	-15 Pa
Minimal gradient (Pa)	-10 PA			-10 Pa		
Oxygen (%)	20.6 %			20.2 %	-	
Carbon dioxide (ppm)	-	320		-	339	

Notes:

% Percent
dB Decibel
Pa Pascal
ppm parts per million
Source: http://www.ihe-online.com/fileadmin/artimg/portable-collapsible-negative-pressure-ic-unit-for-isolation-of-patients-with-airborne-transmissible-diseases.pdf

Figure A-1: IsoArk 220-520 Isolation Chamber and Filtration System (Front View)

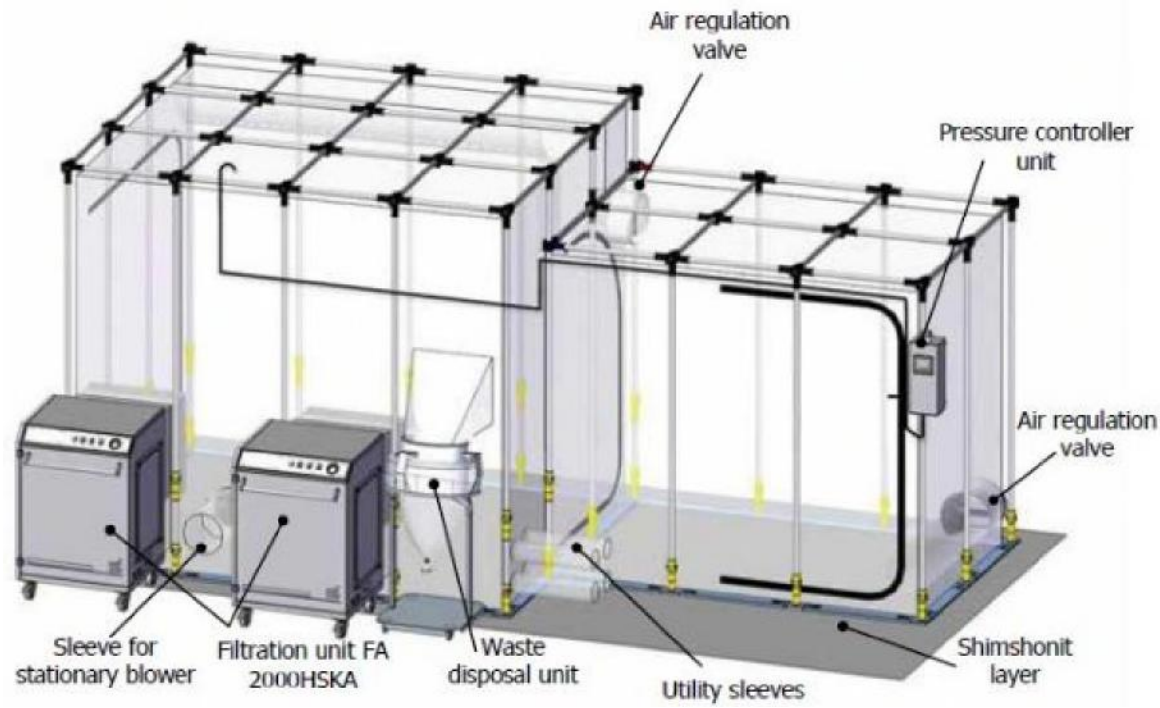
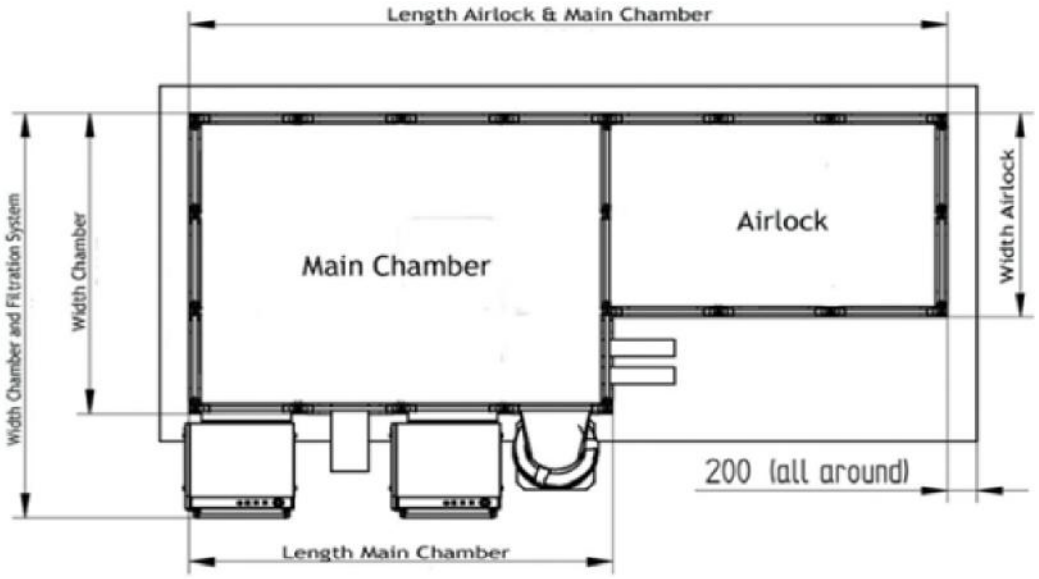


Figure A-2: IsoArk 220-520 Isolation Chamber and Filtration System (Top View)



Ground plan with the general dimensions of the IsoArk 220-520 Isolation Chamber

Chamber Type	*Width Chamber*	*Width Airlock*	*Width Chamber with Filtration System*	*Length Main Chamber*	*Length Chamber with Airlock*
220 X 520	2200mm	1500mm	2950mm	2900mm	5190mm

Table A-2 lists specifications of the IsoArk 220-520 Isolation Chamber.

Table A-2: IsoArk 220-520 Isolation Chamber Specifications

Main Chamber									**Length with Airlock and Open Doors**	
Chamber Type	**Length**		**Width**		**Height**		**Weight**			
	meters (m)	**inches**	**m**	**inches**	**m**	**inches**	**kilograms (kg)**	**pounds (lb)**	**m**	**inches**
90 x 90	2.35	92.5	2.35	92.5	2.35	92.5	50	111	4.65	183
90 x 120	3.1	122	2.35	92.5	2.35	92.5	67	148	4.7	185
120 x 120	3.1	122	3.1	122	2.35	92.5	89	196	4.7	185
120 x 150	3.85	151.5	3.1	122	2.35	92.5	111	245	5.45	215
Airlock (integrated)										
	Length		**Width**		**Height**		**Weight**			
Chamber type	**m**	**inches**	**m**	**inches**	**m**	**inches**	**kg**	**lb**		
all	0.85	33.5	0.85	33.5	2.2	87	included			

Table A-3 lists specifications of the IsoArk 220-520 Isolation Chamber and Filtration System.

Table A-3: IsoArk 220-520 Isolation Chamber and Filtration System Specifications

Filtration System							
Technical Data				**FA 300 HS**	**FA 300 HSA**	**FA 300 HSB**	
Nominal Voltage				230 VAC	115 VAC	100 VAC	
Power Consumption				180 Watt	200 Watt	200 Watt	
Nominal Frequency				50 Hz	60 Hz	60 Hz	
Airflow Rate				300 m^3/h (180 cfm)			
Negative Pressure				≥ 20 Pa			
Noise Level				52 dB			
Filter Efficiency (%)				99.9995%			
Length		**Width**		**Height**		**Weight**	
m	**inches**	**m**	**inches**	**m**	**inches**	**kg**	**lbs**
0.7	27.5	0.4	15.7	0.4	15.7	24	53

Notes:

cfm	Cubic feet per minute
dB	Decibel
Hz	Hertz
kg	Kilograms
lb	Pounds
m	Meter
m^3/h	Cubic meters per hour
Pa	Pascals
VAC	Voltage, alternating current (AC) power

Appendix B: Surface Data

Three concrete and three ceramics surfaces, 1.5 by 2 by 0.15 meters, were used in this test. The concrete surfaces were made from construction grade concrete able to withstand pressures between 10 and 40 Mega-Pascal (MPa) (1450-5800 pounds per square inch [psi]). The concrete test surfaces were composed of, by weight (not by volume), approximately 1 part Portland cement, 2 parts dry sand, 3 parts dry stone, and 1/2 part water. For example, 1 cubic foot (0.028 m^3) of concrete would be made using 22 pounds (lb) cement (equivalent to 10.0 kilograms [kg]), 10 lb (4.5 kg) water, 41 lb (19 kg) dry sand, and 70 lb (32 kg) dry stone (0.5- to 0.75-inch stone), and would weigh approximately 143 pounds (65 kg). The sand used was brick sand (washed and filtered). Organic materials (leaves, twigs, etc.) were removed from the sand and stone to ensure highest strength.

The ceramic surfaces were bought from a local supplier that purchased them from a foreign manufacturer. The tiles meet the Israeli 314 tile standard (based on ISO-14411, ISO-10545 and BS-EN-14411 International standards. The ceramic tiles were installed over a concrete subfloor, 10 cm thick. The setting of the tiles on the concrete surface was conducted using a conventional mortar compound. After all the tiles were set in the mortar and the mortar was dry, the gaps left between the tiles were filled using a mix of grout according to the manufacturer's instructions.

The ceramics technical specifications are listed below:

- MODEL: DENVER 33 (http://www.azteca.es/ficheros_sw/paginas/DENVER_33.pdf)
- SIZE: 33.3 cm X 33.3 cm
- BODY TYPE: BASES GRES PORCELANI

Each batch of concrete and ceramic test surfaces was allowed to cure for at least 30 days in open environment.

The limestone and marble surfaces, 25 mm thick, were bought from a local supplier in Israel [NEGEV 2016]. The limestone and marble surfaces were prepared to meet the Israeli SI-2378 standard (SI-2378 2005), based on the ASTM-E-527-1983-1997 International standards. The limestone and marble surfaces were installed over a concrete subfloor, 10 cm thick. The setting of the surfaces on the concrete surface was conducted using a conventional mortar compound. After all the surfaces were set in the mortar and the mortar was dry, the gaps left between the tiles were filled using a mix of grout according to the manufacturer's instructions. All of the limestone and marble test surfaces were allowed to cure for at least 30 days in open environment.

Appendix C: Experimental Timetables

Test Program 1

The experimental test plan for the radioisotopes 99mTc and 86Rb was implemented at Ramla during January 4-21, 2015. The following (Figure C-1) is the experimental test plan for the radioisotope 137Cs, conducted at NRCN during March 1-12, 2015.

	Gel type	Surface type	Day				
			Sunday 4 Jan	Monday 5 Jan	Tuesday 6 Jan	Wednesday 7 Jan	Thursday 8 Jan
first week 04/01/2015	DeconGel	Ceramics 12	8am Exprinent Set up	10am Measurements	11am ^{99m}Tc Contamination 1pm Measurements 3pm Gel "hot" test		2pm Gel removal 3pm Measurements
	Argon Gel	Ceramics 13	8am Exprinent Set up	8am Measurements 12pm Gel preparation 1pm Gel "cold" test 2pm Gel removal	11am ^{99m}Tc Contamination 3pm Measurements	9am Gel preparation 10am Gel "hot" test 1130am, 1pm, 230pm Gel removal 3pm Measurements	

	Gel type	Surface type	Day				
			Sunday 11 Jan	Monday 12 Jan	Tuesday 13 Jan	Wednesday 14 Jan	Thursday 15 Jan
2nd week 11/01/2015	DeconGel	Concrete 11, Ceramics 12	0910-0920am ^{86}Rb Contamination	8am Measurements	0920am Gel first layer 48h	Day Free	8am Gel removal 9am Measurements 2pm Gel second layer
	Argon Gel	Concrete 21, Ceramics 22	1010-1020am ^{86}Rb Contamination 0100-0600pm Measurements	11am Measurements	0830am Gel preparation 1000-1030am Gel first layer 48h 1140-1200am Gel removal 1pm Measurements	Day Free	1pm Measurements
	DeconGel	Ceramics 13	1110-1120am ^{86}Rb Contamination	1pm Measurements		Day Free	1110am Gel first layer 96h
	Argon Gel	Concrete 23	1120-1130am ^{86}Rb Contamination 12-1pm Lunch	3pm Measurements 12-1pm Lunch	12-1pm Lunch	Day Free	1130am Gel first layer 96h 1300pm Gel removal 3pm Measurements 12-1pm Lunch

	Gel type	Surface type	Day				
			Sunday 18 Jan	Monday 19 Jan	Tuesday 20 Jan	Wednesday 21 Jan	Thursday 22 Jan
3rd week 18/01/2015	DeconGel	Concrete 11, Ceramics 12	0810-0830am Gel removal 10am Measurements		8am site cleaning	8am site cleaning	
	Argon Gel	Concrete 21, Ceramics 22	9am Gel preparation 0940-1020am Gel second layer 1110-1150am Gel removal	9am Measurements	8am site cleaning	8am site cleaning	
	Decongel	Ceramics 13	0830am Gel removal 3pm Measurements		8am site cleaning	8am site cleaning	
	Argon Gel	Concrete 23	1030am Gel second layer 1200-1220pm Gel removal 12-1pm Lunch	3pm Measurements 12-1pm Lunch	8am site cleaning	8am site cleaning	

Gel type	Surface type	Day				
		Sunday* 1/3/15	Monday 2/3/15	Tuesday 3/3/15	Wednesday 4/3/15	Thursday 5/3/15
DeconGel	Concrete 11, Ceramics 12	0100pm Measurements	0900am Measurements 1230pm ^{137}Cs Contamination	0900am Measurements	1230pm Gel first layer 48h	Holiday
Argon Gel	Concrete 21, Ceramics 22	0200pm Measurements	1100am Measurements 0100pm ^{137}Cs Contamination	1100am Measurements	1000am Gel preparation 0100pm Gel first layer 48h 0230pm Gel removal 0300pm Measurements	Holiday
		1200-0100pm Lunch	0100-0200pm Lunch	1200-0100pm Lunch	0100-0200pm Lunch	1200-0100pm Lunch

Gel type	Surface type	Day				
		Sunday 8/3/2015	Monday 9/3/2015	Tuesday 10/3/2015	Wednesday 11/3/2015	Thursday 12/3/2015
DeconGel	Concrete 11, Ceramics 12	0900am Gel removal 1000am Measurements 0200pm Gel second layer	Free day	0200pm Gel removal 0300pm Measurements	0900am site cleaning	0900am site cleaning
Argon Gel	Concrete 21, Ceramics 22	0830am Gel preparation 1000am Gel second layer 1130am Gel removal 0100pm Measurements	Free day		0900am site cleaning	0900am site cleaning
		1200-0100pm Lunch	1200-0100pm Lunch	1200-0100pm Lunch	1200-0100pm Lunch	1200-0100pm Lunch

Figure C-1. The experimental test plan for the radioisotope ^{137}Cs, conducted at NRCN, March 1-12, 2015

Test Program 2

Figure C-2 is the experimental test plan for the first week, November 8-12, 2015.

	Surface type	Day				
		Sunday 8 Nov*	Monday 9 Nov	Tuesday 10 Nov	Wednesday 11 Nov	Thursday 12 Nov
1st week 8-12/11/15 Tent 1 DeconGel	Concrete 11	1030am ^{86}Rb Contamination 0130pm Measurements		1030am DG first layer		0915am Gel removal 1000am Measurements 0100pm DG second layer
	Marble 12	1040am ^{86}Rb Contamination 0200pm Measurements		1040am DG first layer		0945am Gel removal 1100am Measurements 0300pm DG second layer
	LimeStone 13	1050am ^{86}Rb Contamination 0230pm Measurements		1050am DG first layer		1045am Gel removal 0130pm Measurements 0500pm DG second layer

	Surface type	Day				
		Sunday 8 Nov	Monday 9 Nov	Tuesday 10 Nov	Wednesday 11 Nov	Thursday 12 Nov
1st week 8-12/11/15 Tent 2 Argonne SuperGel	Concrete 21	0130pm ^{86}Rb Contamination	0930am Measurements	0345pm Gel preparation 0415pm ASG first layer 0130pm Gel removal	0930am Measurements	
	Marble 22	0140pm ^{86}Rb Contamination	1010am Measurements	0330pm ASG first layer 0400pm Gel removal	1010am Measurements	
	LimeStone 23	0150pm ^{86}Rb Contamination	1045am Measurements	0300pm ASG first layer 0330pm Gel removal	1100am Measurements	

Figure C-2. Experimental test plan for the first week, November 8-12, 2015

Figure C-3 is the experimental test plan for the second week, November 15-19, 2015.

	Surface type	Day				
		Sunday 15 Nov	Monday 16 Nov	Tuesday 17 Nov	Wednesday 18 Nov	Thursday 19 Nov
2nd week 15-19/11/15 Tent 1 DeconGel	Concrete 11	0930am Gel removal 0940am Measurements	8am site cleaning	8am site cleaning		
	Marble 12	0940am Gel removal 1030am Measurements	8am site cleaning	8am site cleaning		
	LimeStone 13	1000am Gel removal 1120am Measurements	8am site cleaning	8am site cleaning		

	Surface type	Day				
		Sunday 15 Nov	Monday 16 Nov	Tuesday 17 Nov	Wednesday 18 Nov	Thursday 19 Nov
2nd week 15-19/11/15 Tent 2 Argonne SuperGel	Concrete 21	0100pm Gel preparation 0220pm ASG second layer 0250pm Gel removal 0310pm Measurements	8am site cleaning	8am site cleaning		
	Marble 22	0200pm ASG second layer 0230pm Gel removal 0400pm Measurements	8am site cleaning	8am site cleaning		
	LimeStone 23	0145pm ASG second layer 0215pm Gel removal 0500pm Measurements	8am site cleaning	8am site cleaning		

Figure C-3. Experimental test plan for the second week, November 15-19, 2015

Appendix D: ^{99m}Tc results

Some of the preliminary results obtained at the Ramla site during the tests using the radioisotope ^{99m}Tc (January 4-8, 2015) are presented in this appendix. All of these tests were conducted in Isolation Chamber No. 1, using DeconGel™ and two surfaces: surface 12 (ceramic) and 13 (concrete). The ^{99m}Tc was prepared in spray bottles, identical to the ones used later for the ^{86}Rb and ^{137}Cs tests. The DeconGel™ was sprayed on the surfaces by use of the electrical sprayer depicted on Figure 2-10, and was left to dry for 48 hours before removal. Radiation from the surfaces was measured by use of the 2" NaI(Tl) detector, shown on Figure 2-5, and the results were recorded by use of the system depicted on Figure 2-6. Measurements recorded from surfaces 12 and 13 are depicted on Figure D-1 and Figure D-2, respectively. All results shown on these pictures were not corrected for the isotope radioactive decay, half-life of 6.0067 hr (time was not recorded in these preliminary tests). Therefore, %Rs shown are much higher than the real values that would have been calculated if this correction had been made.

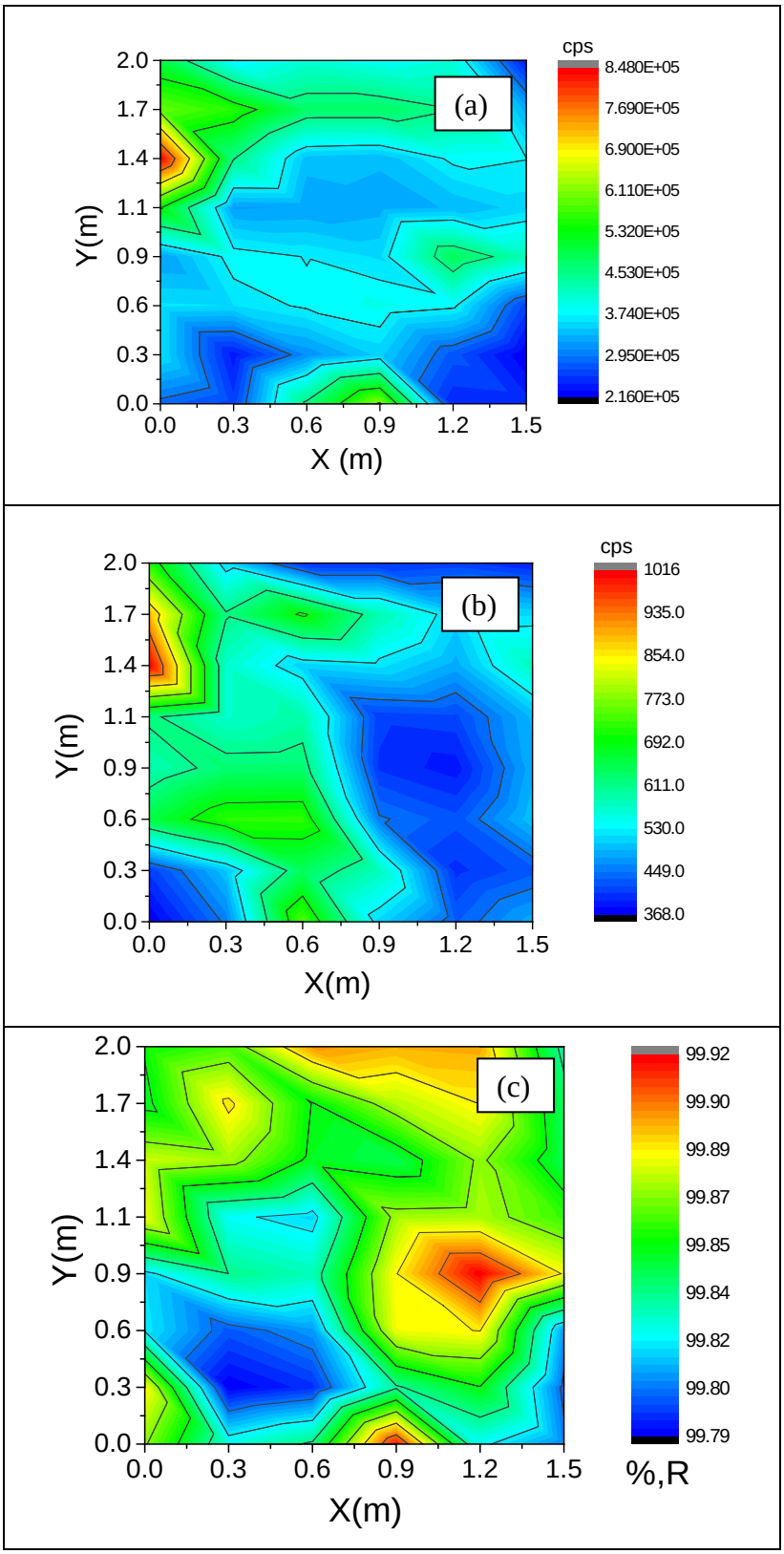


Figure D-1. ^{99m}Tc contamination measurement map of (a) ^{99m}Tc preliminary contamination level, (b) ^{99m}Tc contamination level after the 1st decontamination process and (c) calculated %R after the 1st decontamination process, for surface 12 (Ceramics DeconGel™), measured with the 2" NaI(Tl) detector

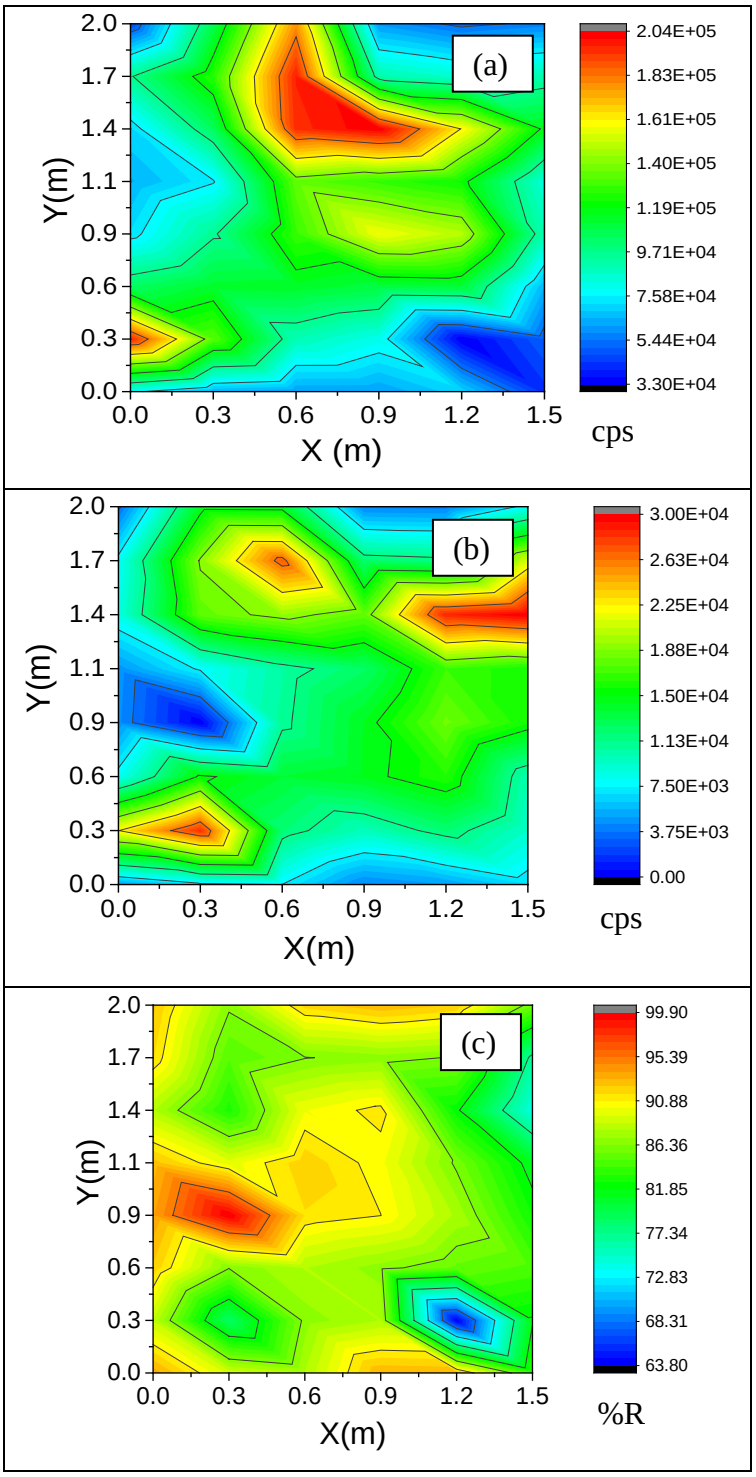


Figure D-2. ^{99}mTc contamination measurement map of (a) ^{99}mTc preliminary contamination level, (b) ^{99m}Tc contamination level after the 1st decontamination process and (c) calculated %R after the 1st decontamination process, for surface 13 (Concrete DeconGel™), measured with the 2" NaI(Tl) detector

Two of the pictures taken during the work conducted with the ^{99m}Tc radioisotope are shown on Figures D-3 and D-4 below as examples of complications in working with this short half-life radioisotope. To allow reasonable measurements of contamination remaining on the surfaces after 48 hours (about 8 half-lives of this radioisotope), an activity of 100 mCi ^{99m}Tc was used in these tests. Therefore, all work in these chambers before removal of the DeconGel™ occurred with use of lead aprons. As shown on the figures below, work with this shield was complicated and hard to conduct compared to work with the much lower activity used during the ^{86}Rb and ^{137}Cs tests.

Figure D-3. Preparations for spraying of the DeconGel™

Figure D-4. Spraying the DeconGel™ on surface 12

Appendix E Test Program 1 Results

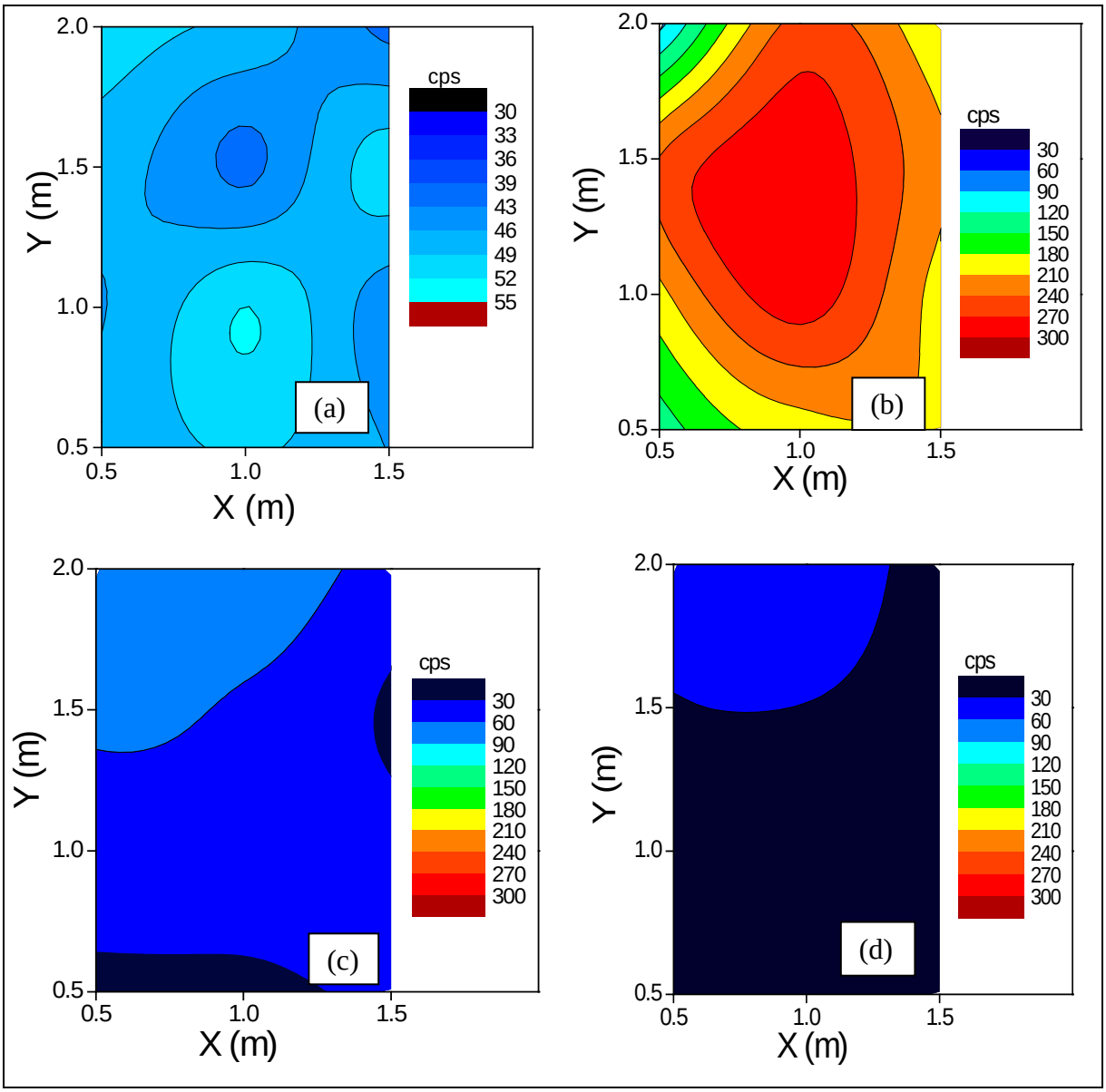


Figure E-1. ^{86}Rb contamination measurement map of (a) background, (b) preliminary contamination level, (c) contamination level after the first decontamination process, and (d) contamination level after the second decontamination process, for surface 12 (Ceramics DeconGel™), measured with the NaI(Tl) 2" detector

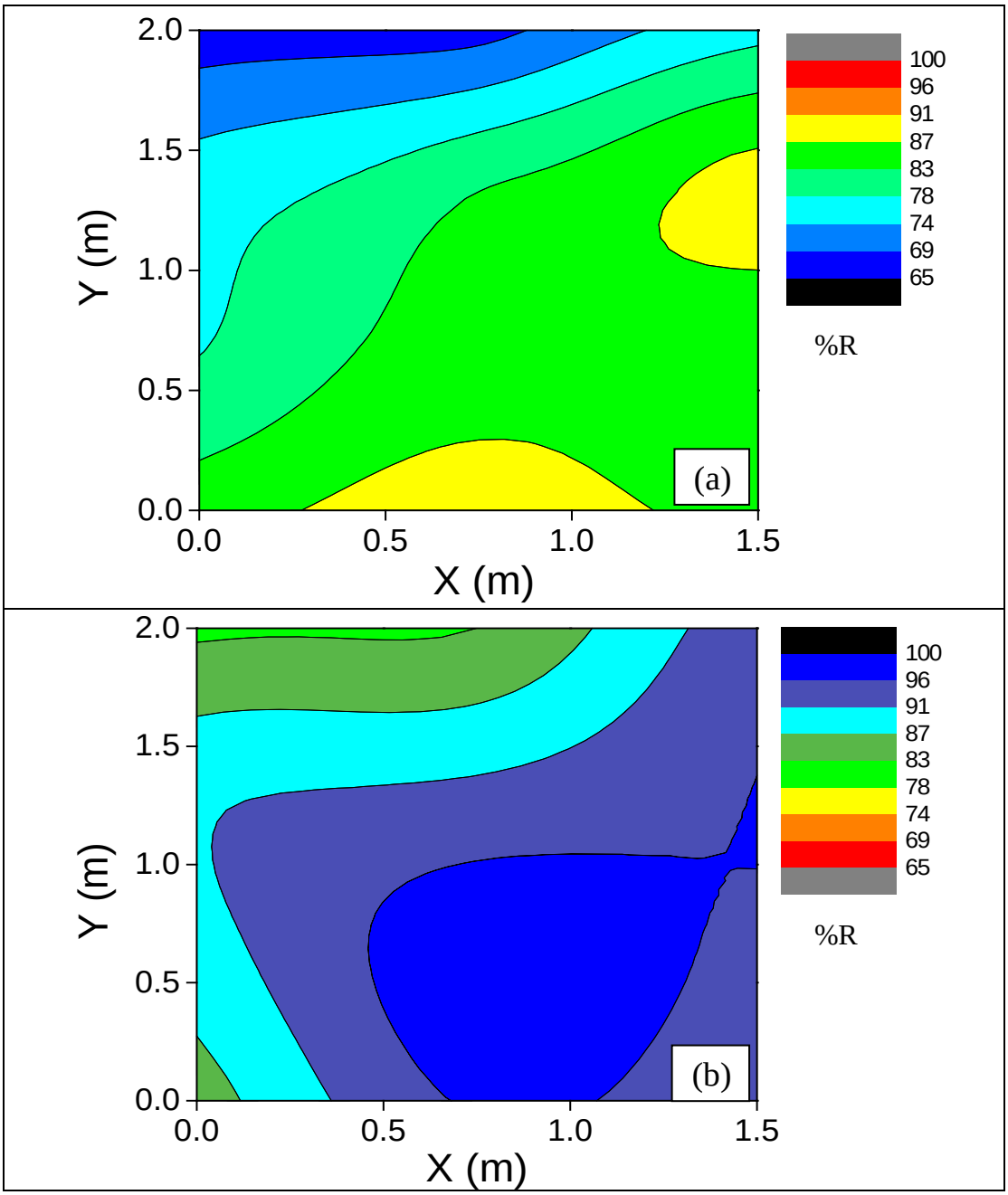


Figure E-2. The ^{86}Rb calculated %R map plotted after the (a) first and (b) second decontamination process, for surface 12 (Ceramics DeconGel™)

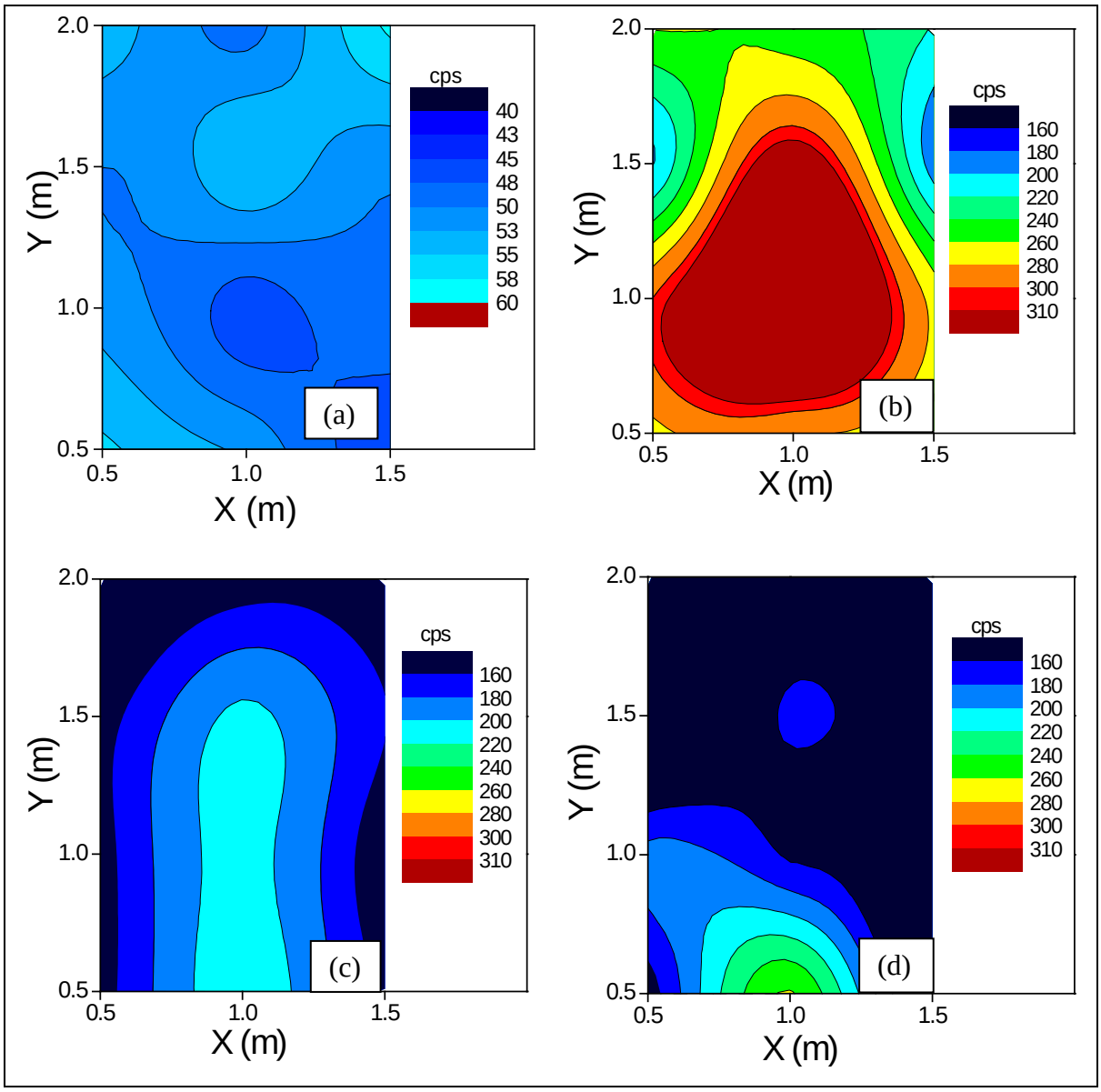


Figure E-3. ^{86}Rb contamination measurements map of (a) background,(b) preliminary contamination level, (c) contamination level after the first decontamination process, and (d) contamination level after the second decontamination process, for surface 21 (Concrete, EAI Supergel), measured with the NaI(Tl) 2" detector

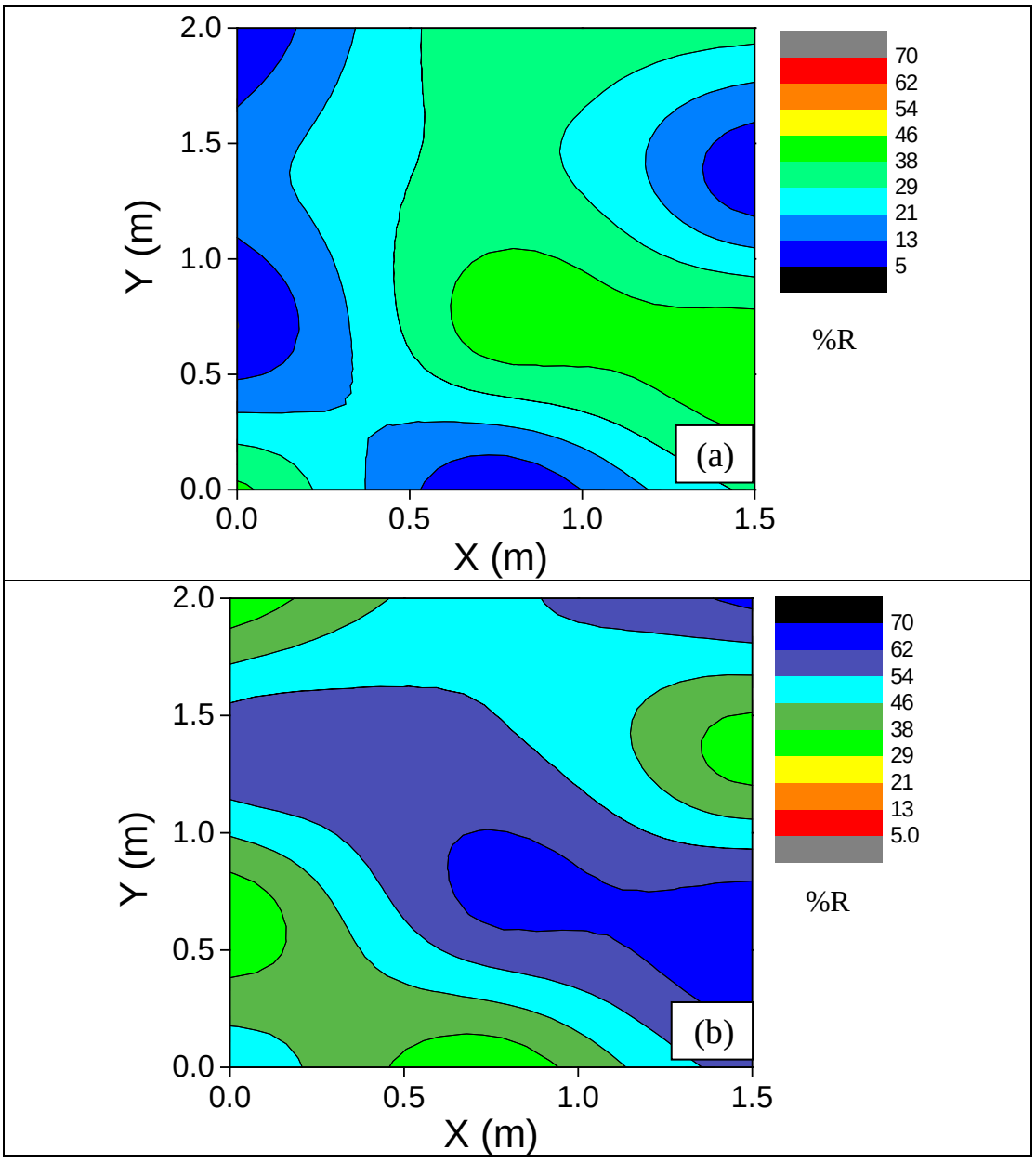


Figure E-4. The ^{86}Rb calculated %R map plotted after the (a) first and (b) second decontamination processes, for surface 21 (Concrete, EAI Supergel)

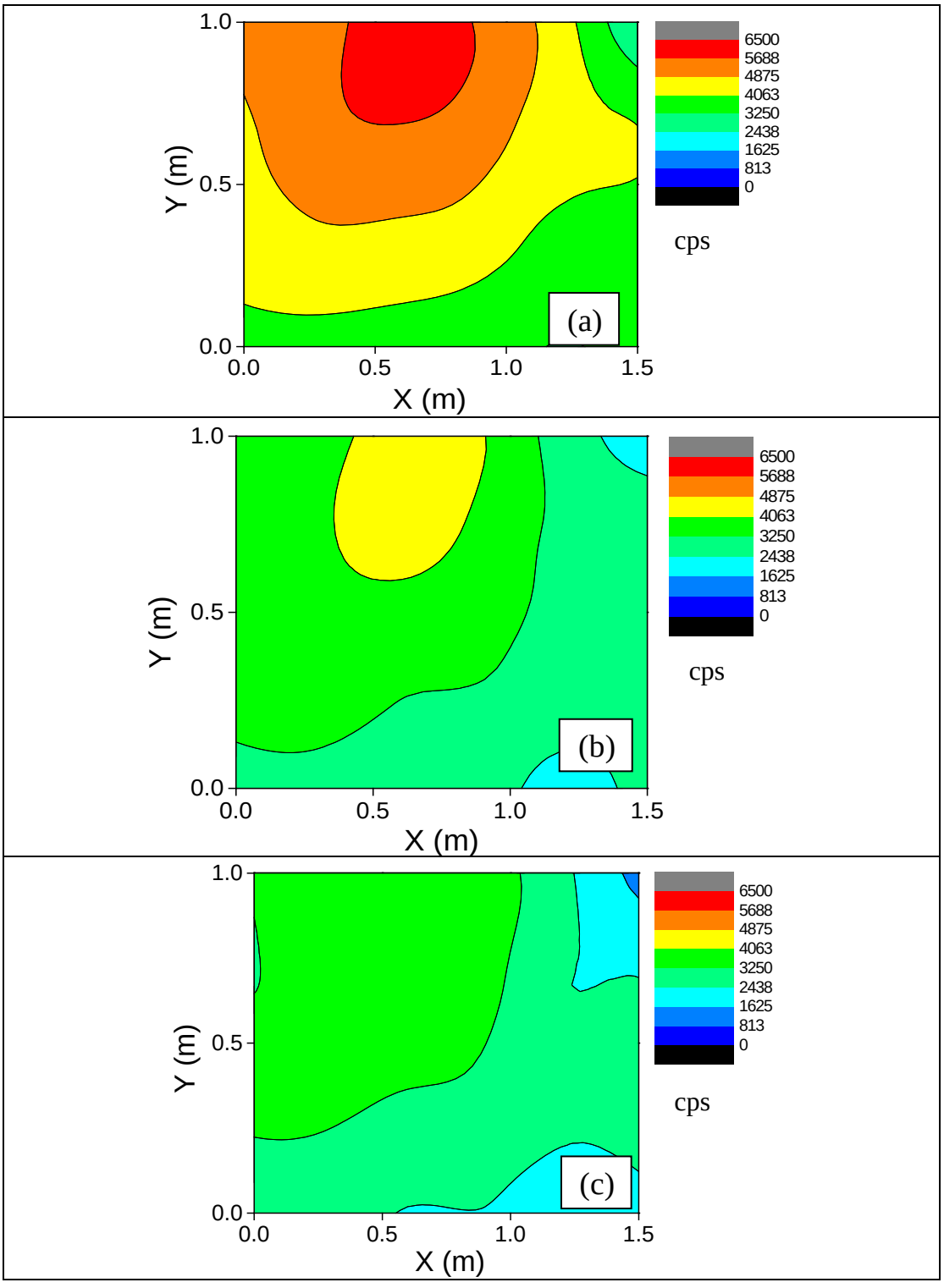


Figure E-5. The ^{137}Cs contamination measurements map of (a) preliminary contamination level, (b) contamination level after the first decontamination process, and (c) contamination level after the second decontamination process, for surface 11 (Concrete, DeconGel™), measured with the NaI(Tl) 2" detector

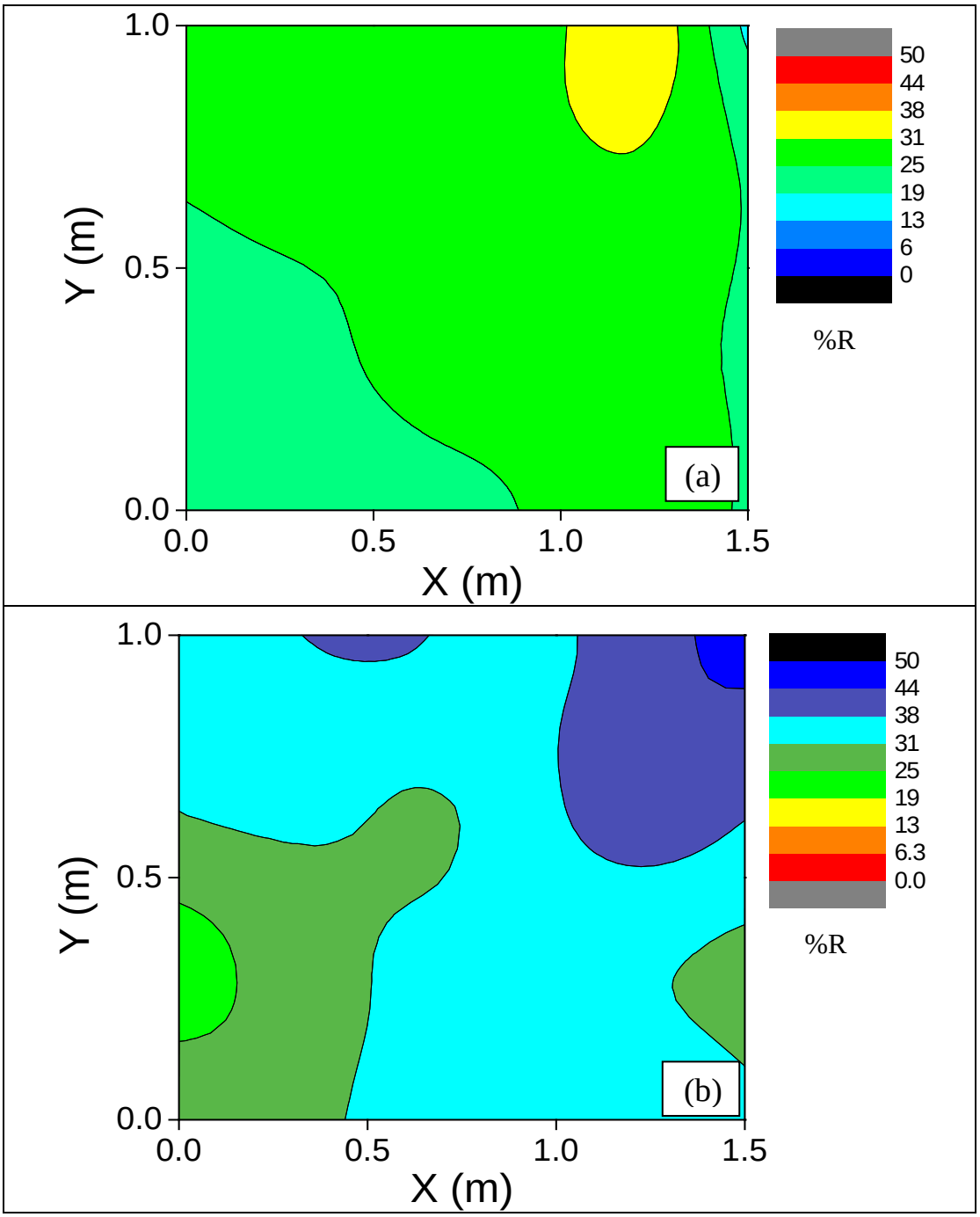


Figure E-6. The ^{137}Cs calculated %R map plotted after the (a) first and (b) second decontamination processes, for surface 11 (Concrete, DeconGel™)

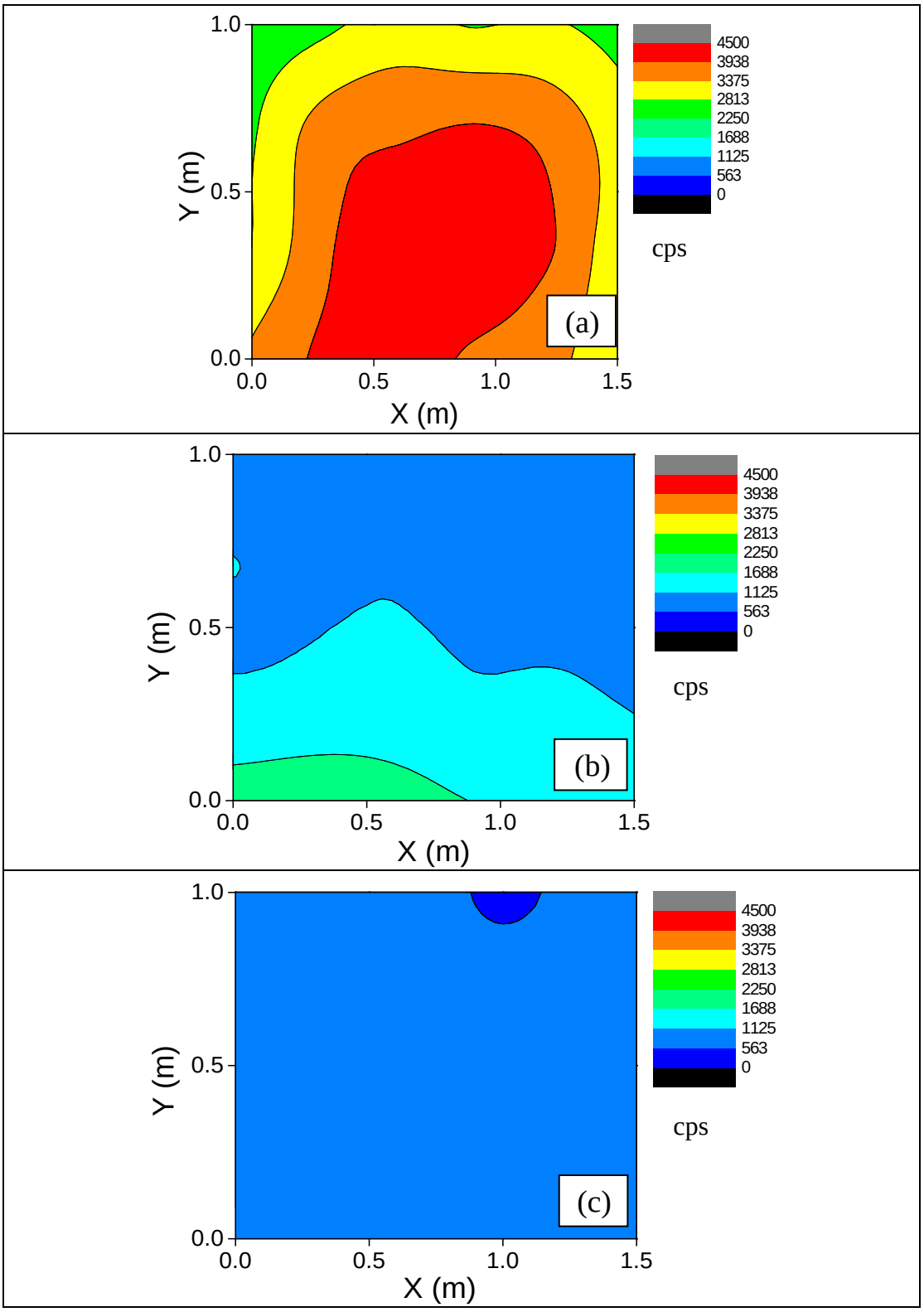


Figure E-7. ^{137}Cs contamination measurements map of (a) preliminary contamination level, (b) contamination level after the first decontamination process and (c) contamination level after the second decontamination process, for surface 12 (Ceramics, DeconGelTM), measured with the NaI(Tl) 2" detector

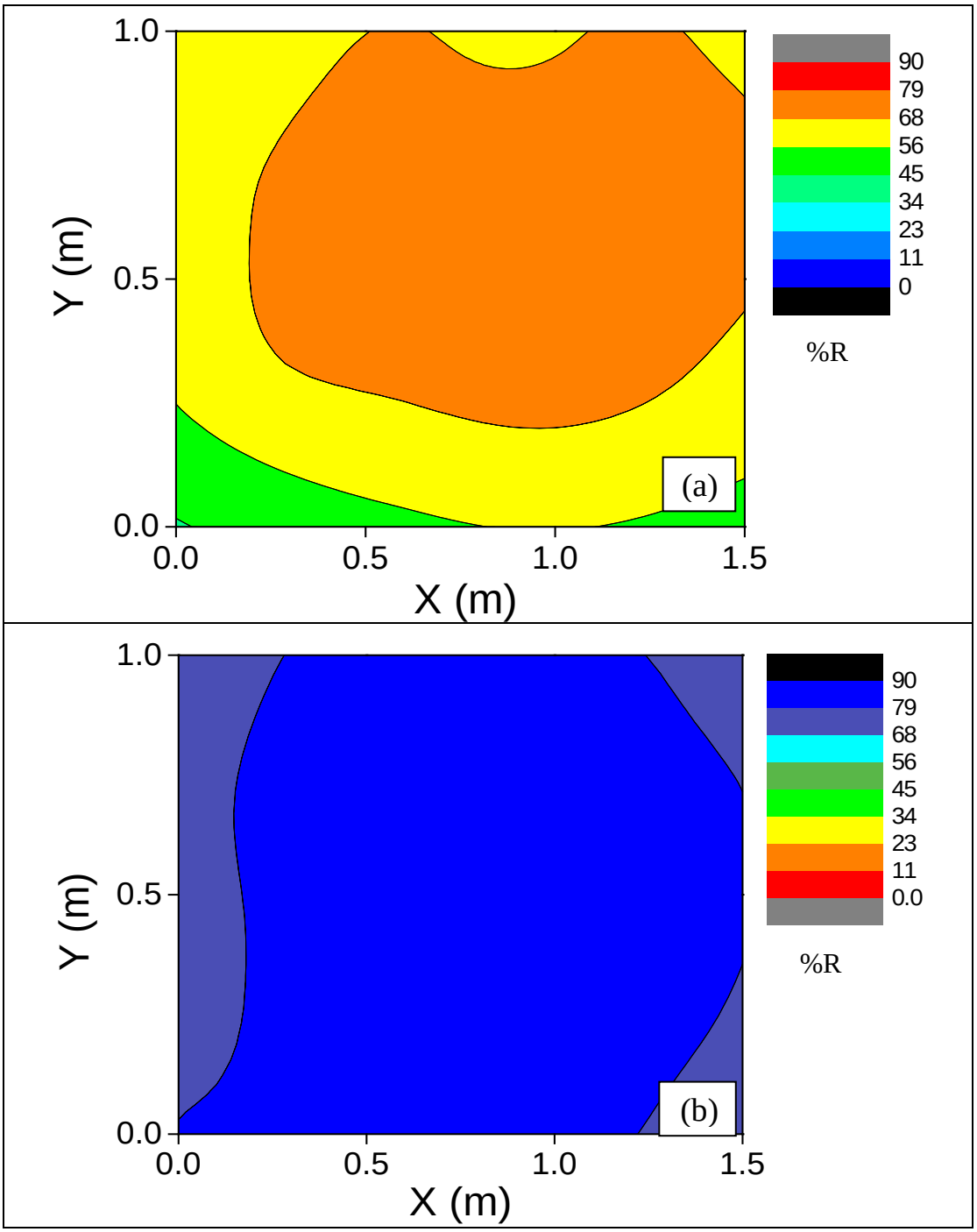


Figure E-8. The ^{137}Cs calculated %R map plotted after the (a) first and (b) second decontamination processes, for surface 12 (Ceramics, DeconGel™)

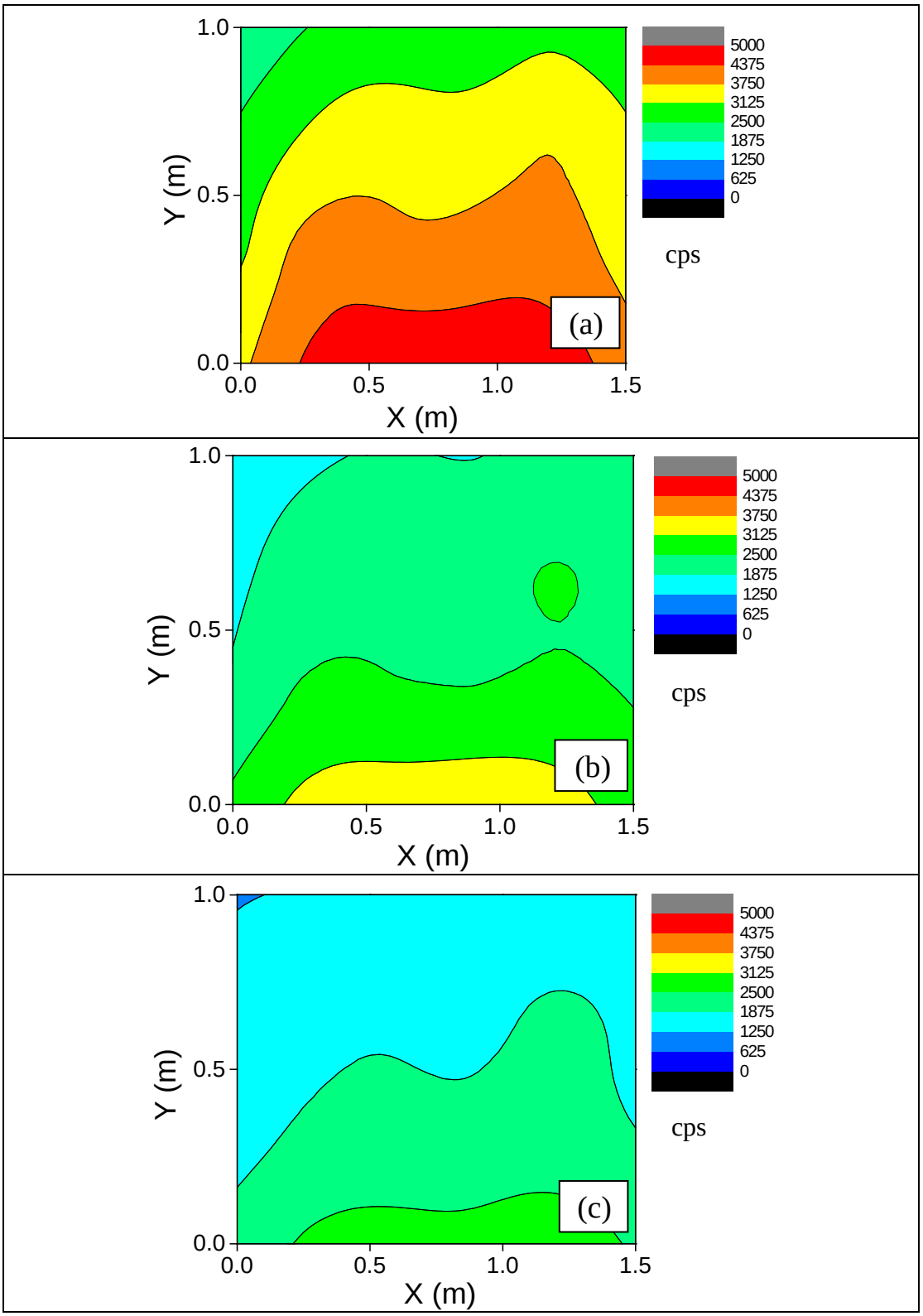


Figure E-9. ^{137}Cs contamination measurements map of (a) preliminary contamination level, (b) contamination level after the first decontamination process and (c) contamination level after the second decontamination process, for surface 21 (Concrete, EAI Supergel), measured with the NaI(Tl) 2" detector

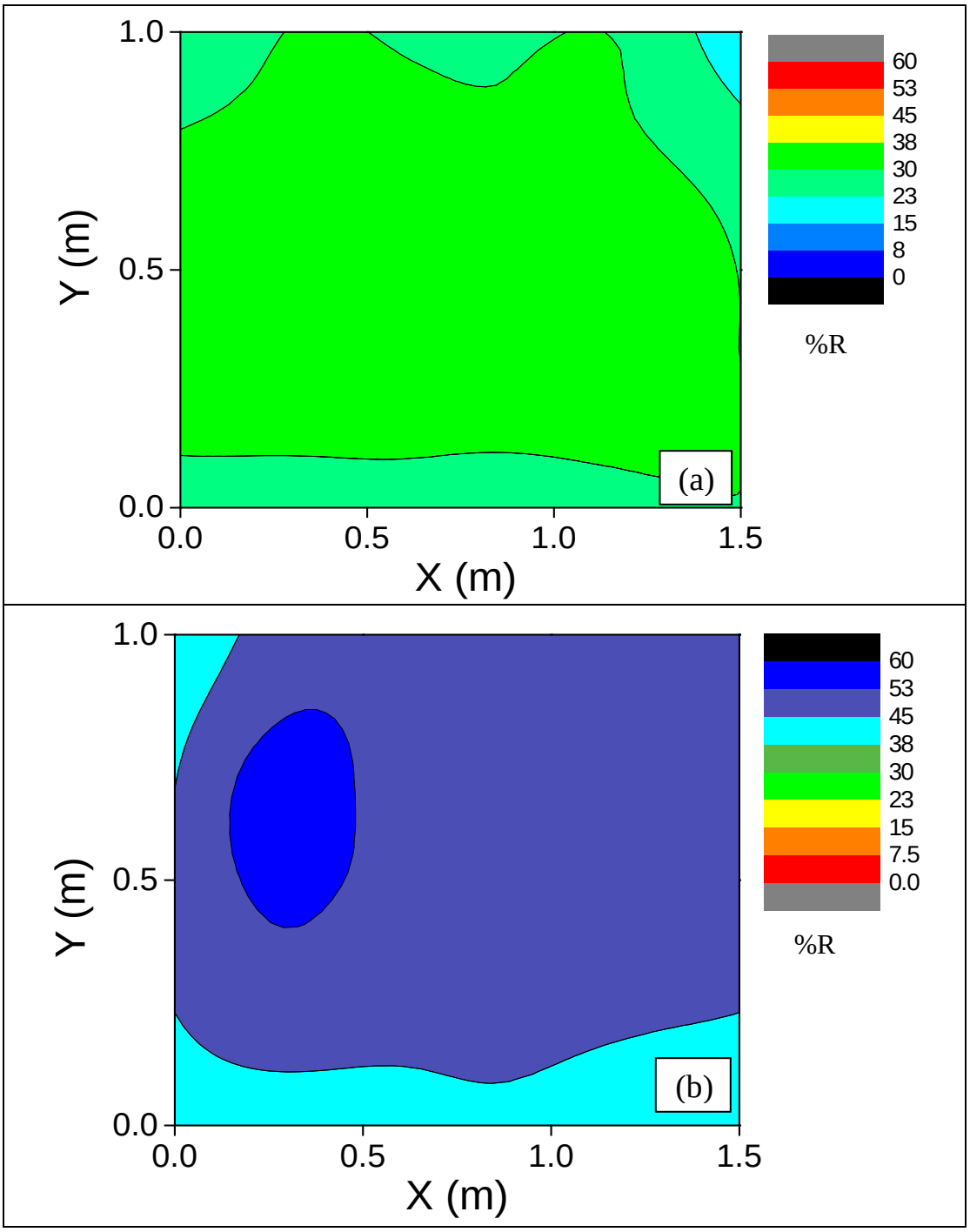


Figure E-10. The ^{137}Cs calculated %R map plotted after the (a) first and (b) second decontamination processes, for surface 21 (Concrete, EAI Supergel)

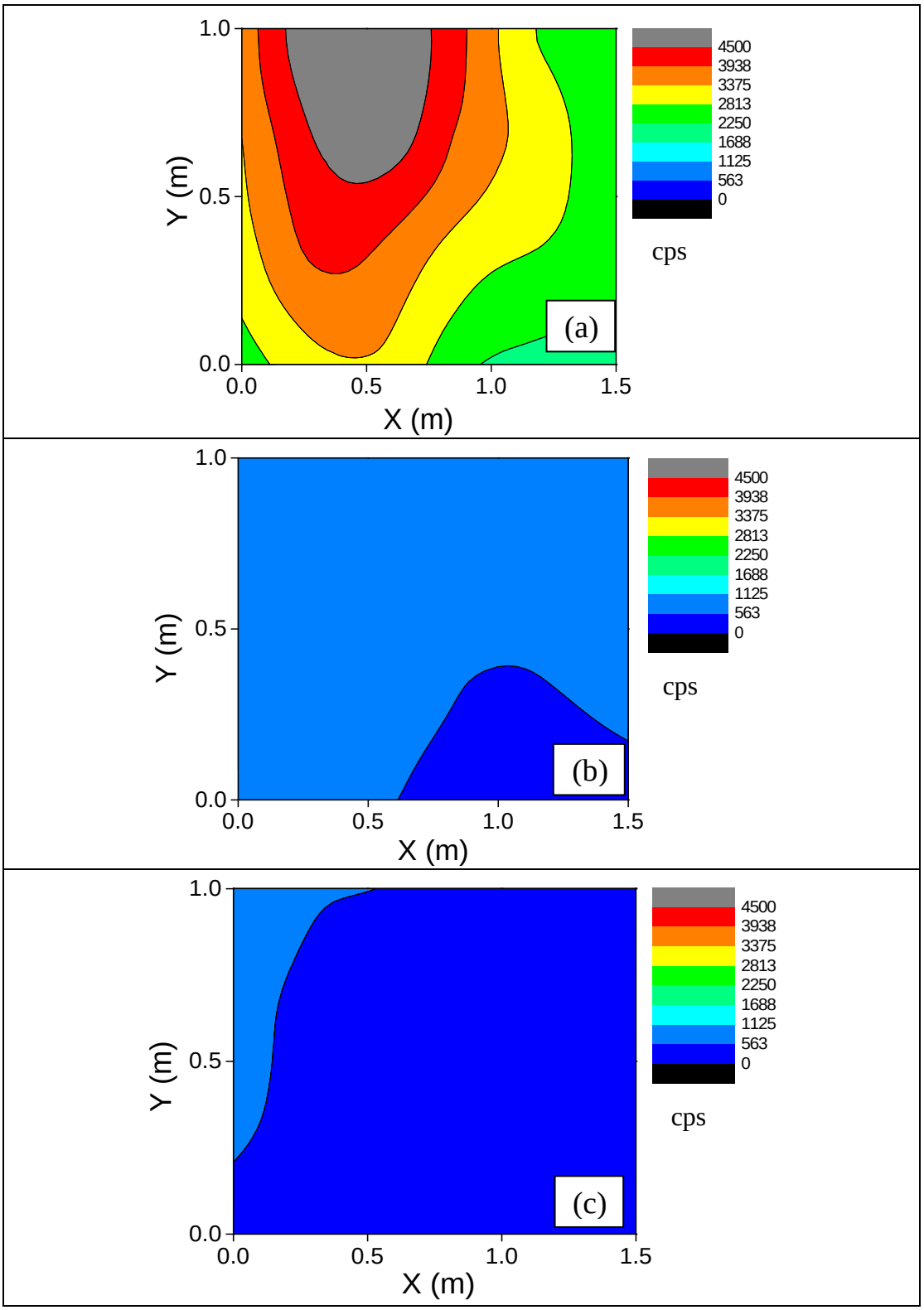


Figure E-11. ^{137}Cs contamination measurements map of (a) preliminary contamination level, (b) contamination level after the first decontamination process and (c) contamination level after the second decontamination process, for surface 22 (Ceramics, EAI Supergel), measured with the NaI(Tl) 2" detector

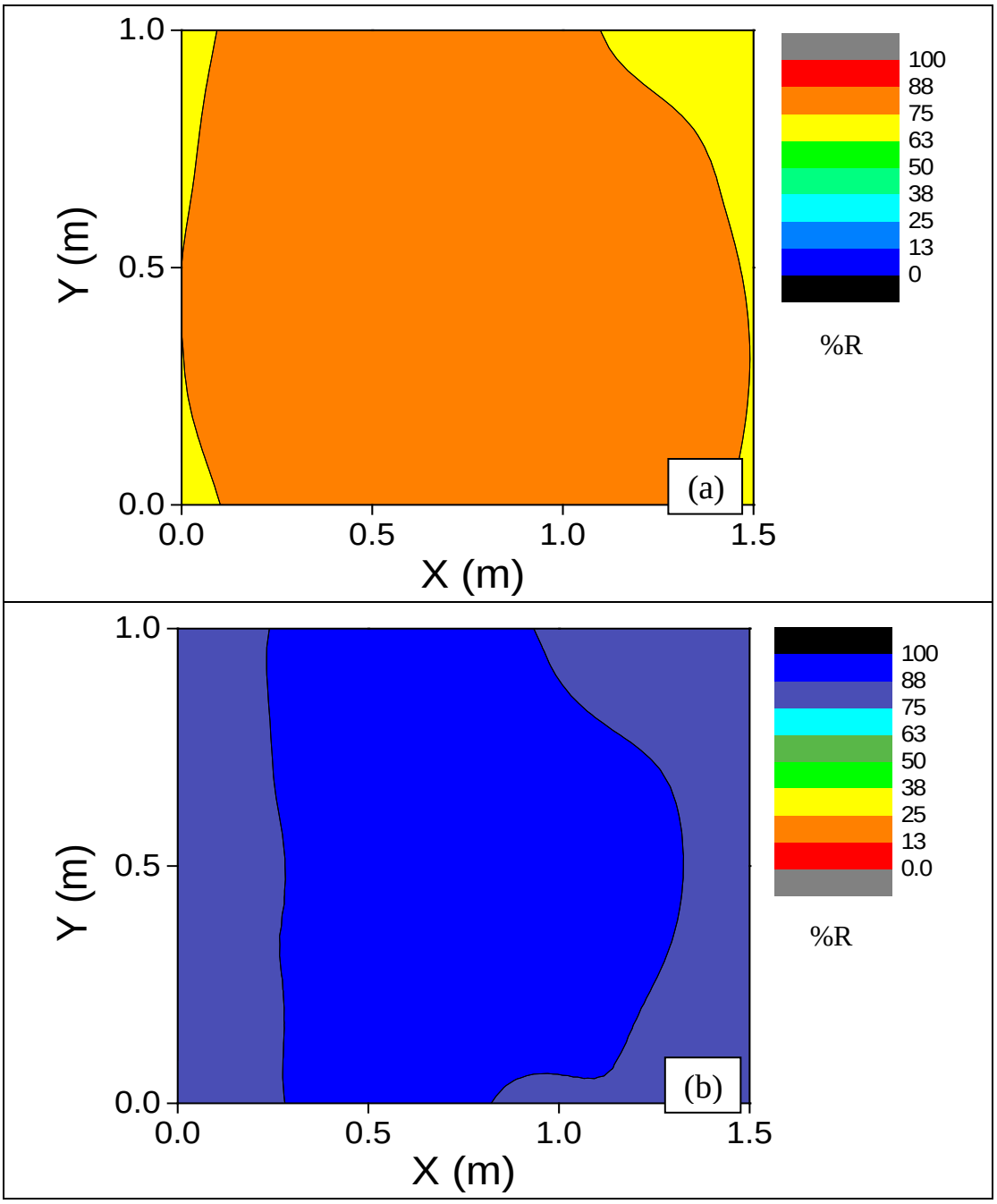


Figure E-12. The ^{137}Cs calculated %R map plotted after the (a) first and (b) second decontamination processes, for surface 21 (Ceramics, EAI Supergel)

Appendix F Test Program 2 Results

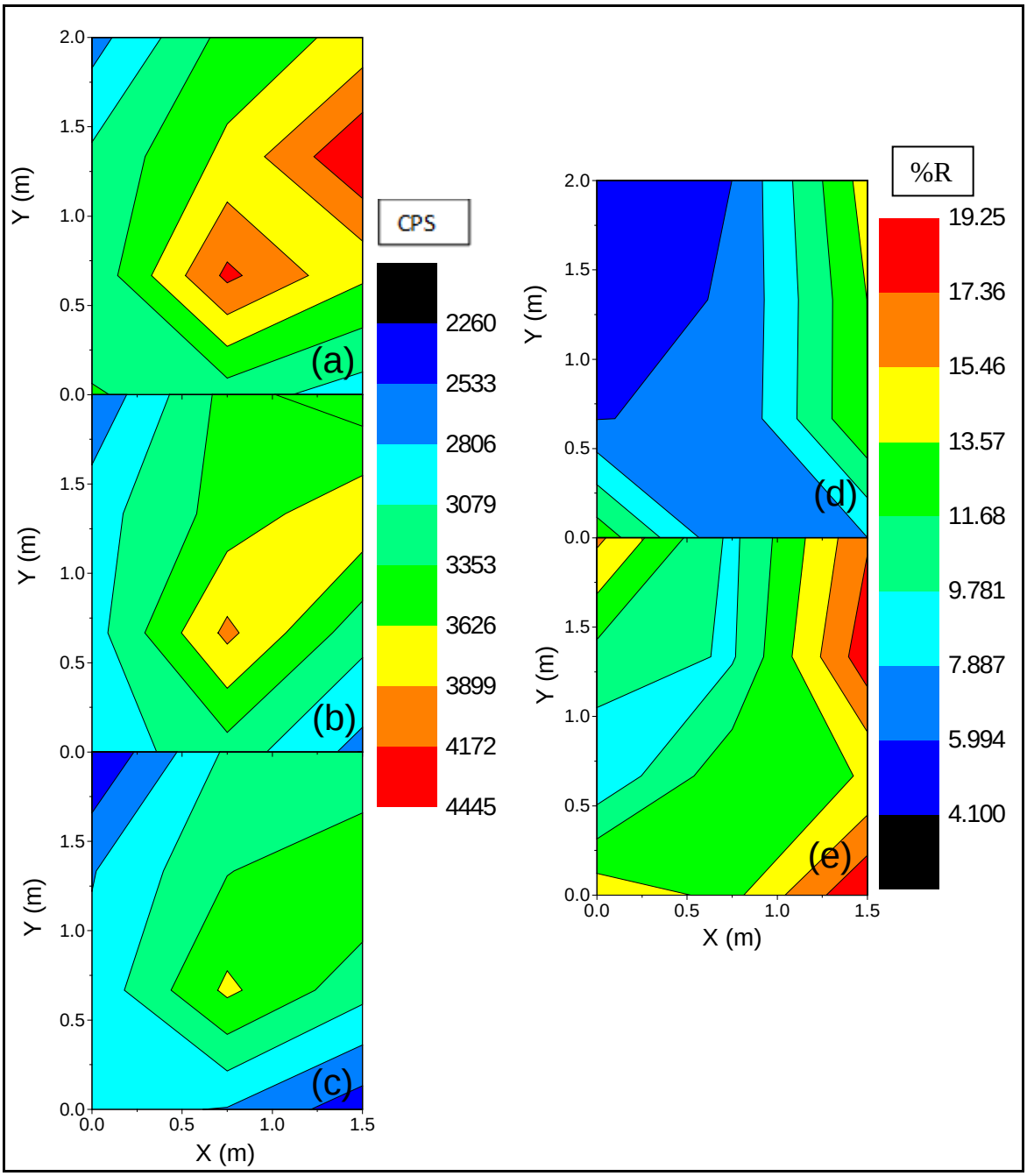


Figure F-1. Contamination measurement results for surface 11 (concrete – DeconGel™): (a) preliminary contamination level, (b) and (c) contamination levels after the first and second decontamination processes, respectively, (d) and (e) calculated %R values plotted after the first and second decontamination processes, respectively, measured with the NaI(Tl) 2" detector

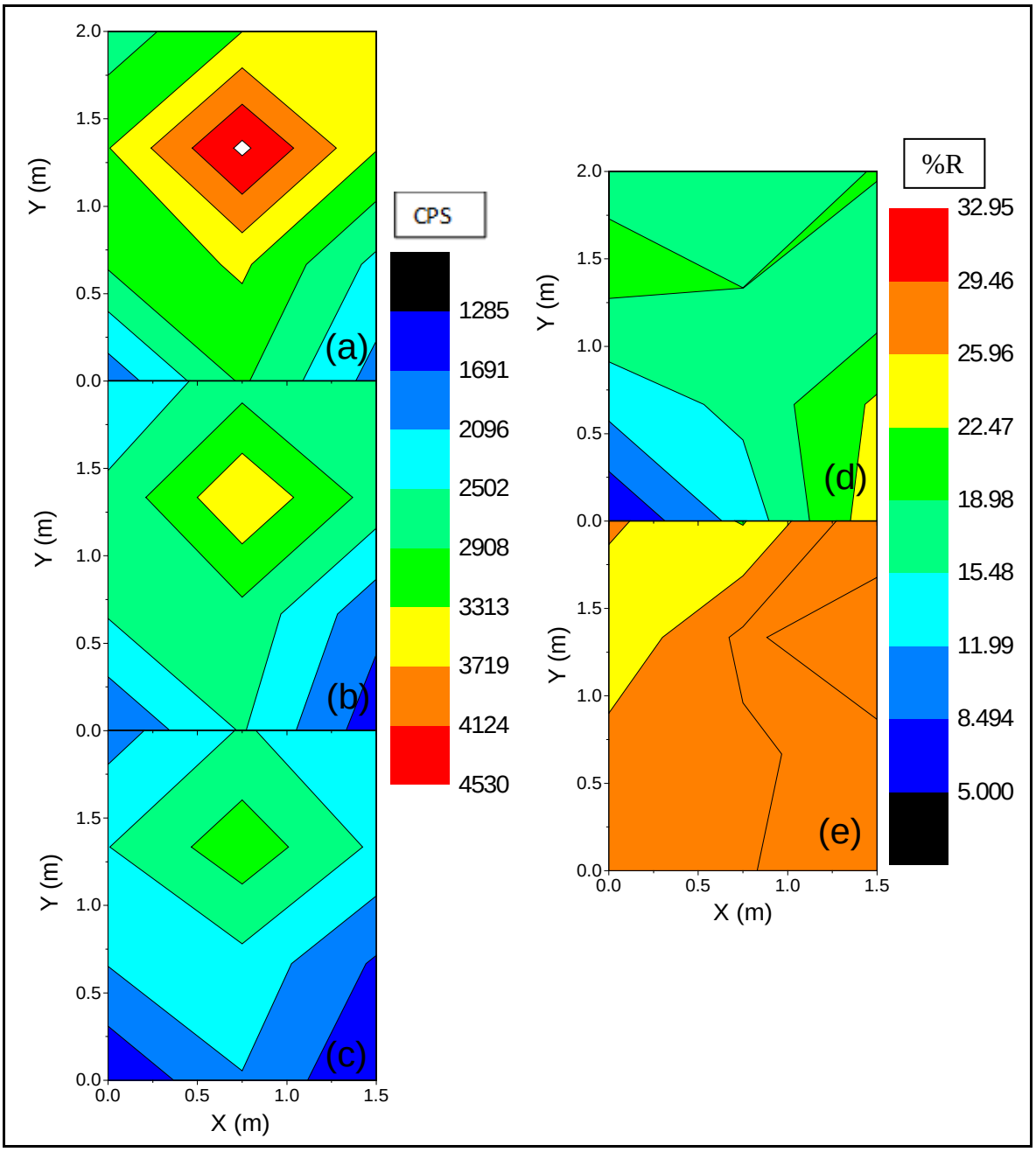


Figure F-2. Contamination measurement results for surface 12 (marble – DeconGel™): (a) preliminary contamination level, (b) and (c) contamination levels after the first and second decontamination processes, respectively, (d) and (e) calculated %R values plotted after the first and second decontamination processes, respectively, measured with the NaI(Tl) 2" detector

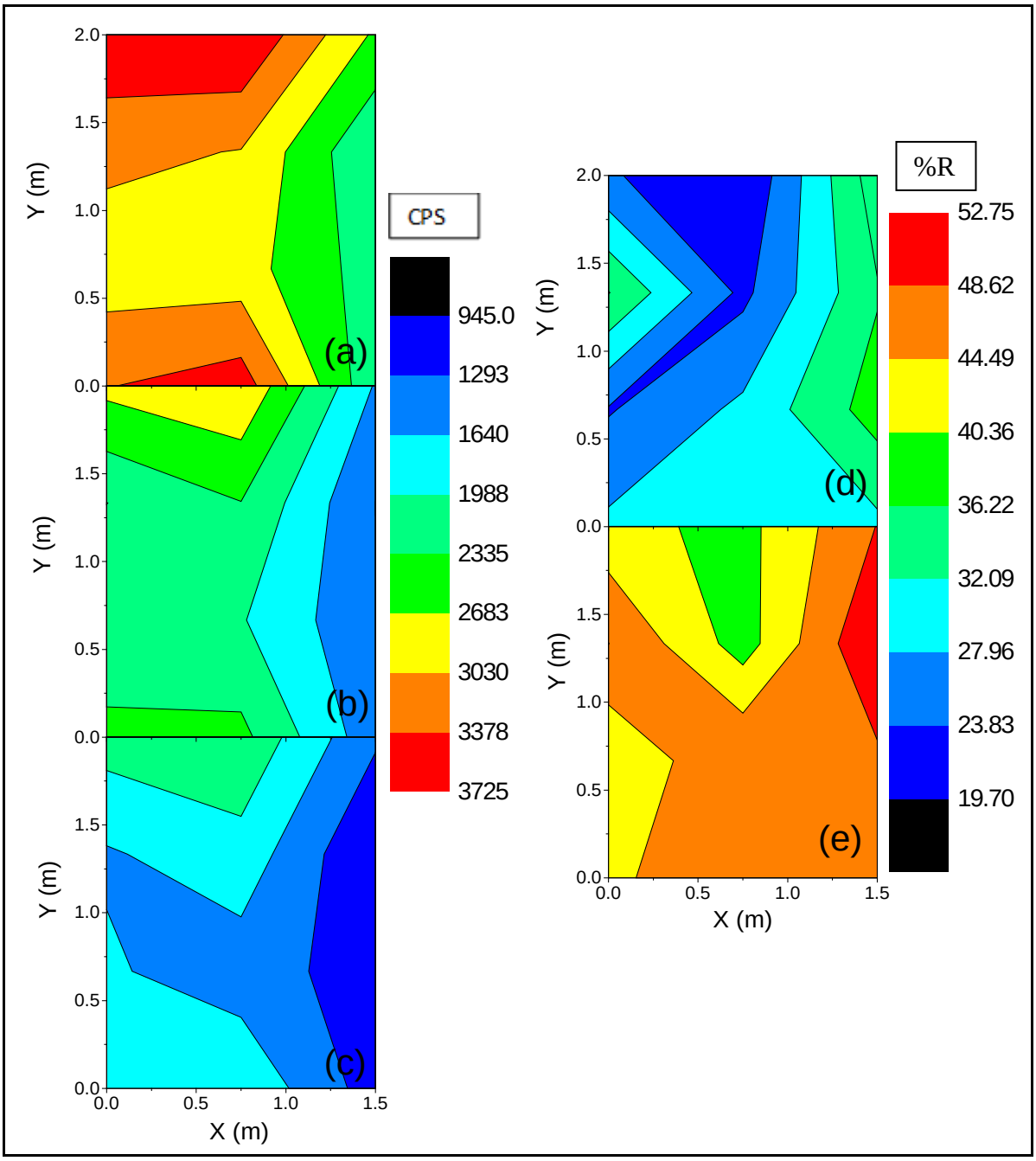


Figure F-3. Contamination measurement results for surface 13 (limestone – DeconGel™): (a) preliminary contamination level, (b) and (c) contamination levels after the first and second decontamination processes, respectively, (d) and (e) calculated %R values plotted after the first and second decontamination processes, respectively, measured with the NaI(Tl) 2" detector

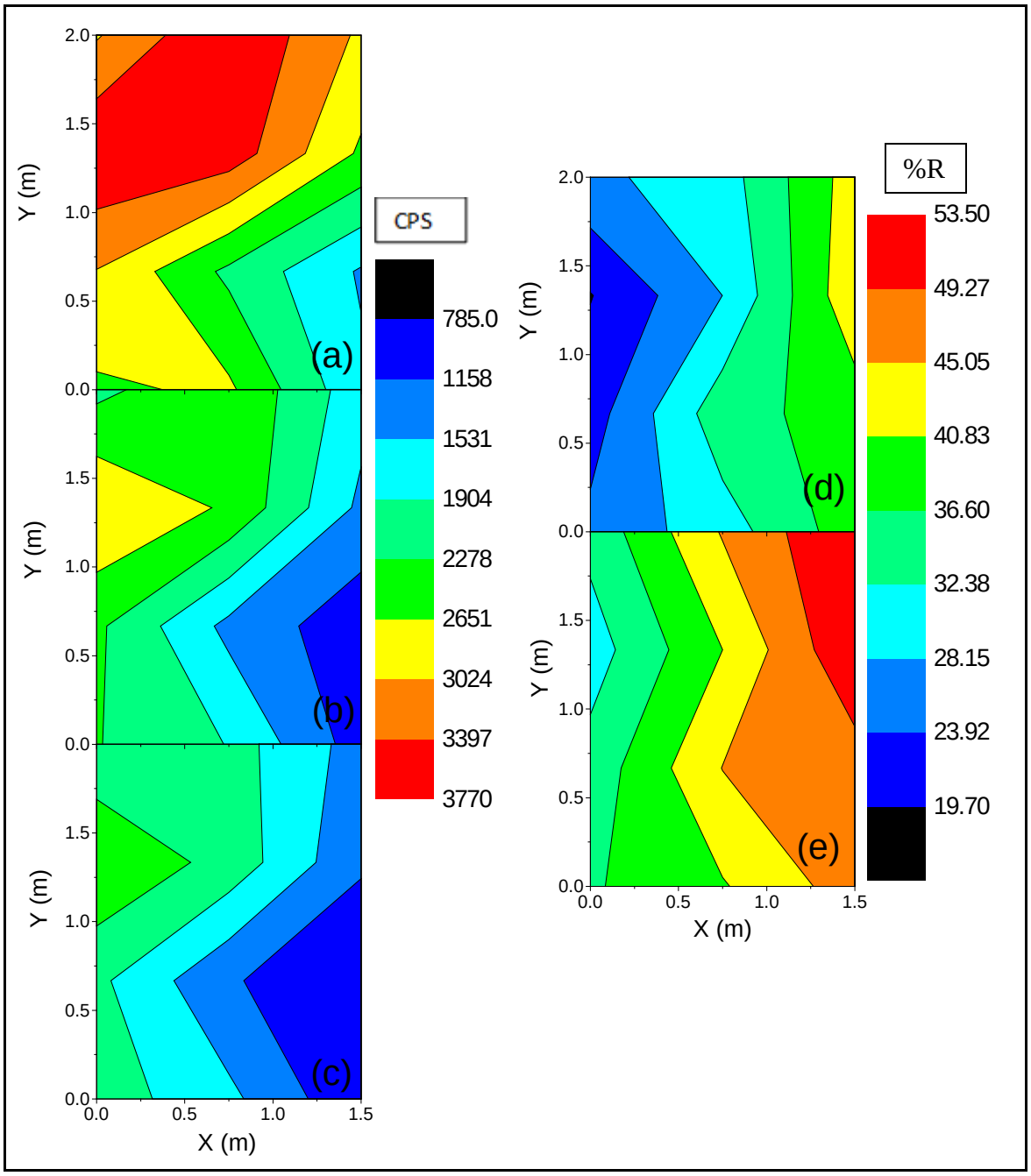


Figure F-4. Contamination measurement results for surface 21 (concrete – EAI Supergel): (a) preliminary contamination level, (b) and (c) contamination levels after the first and second decontamination processes, respectively, (d) and (e) calculated %R values plotted after the first and second decontamination processes, respectively, measured with the NaI(Tl) 2" detector

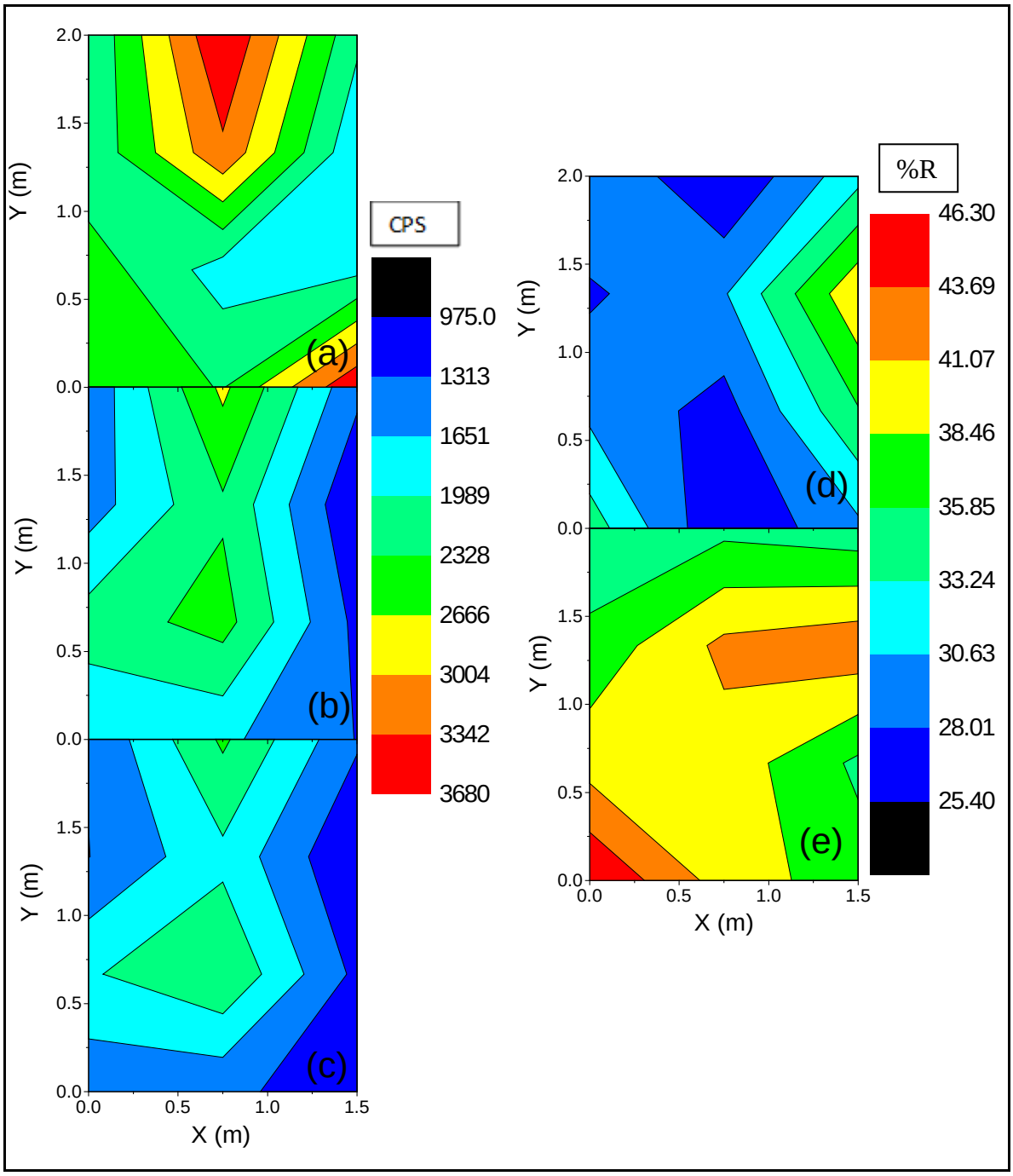


Figure F-5. Contamination measurement results for surface 22 (marble – EAI Supergel): (a) preliminary contamination level, (b) and (c) contamination levels after the first and second decontamination processes, respectively, (d) and (e) calculated %R values plotted after the first and second decontamination processes, respectively, measured with the NaI(Tl) 2" detector

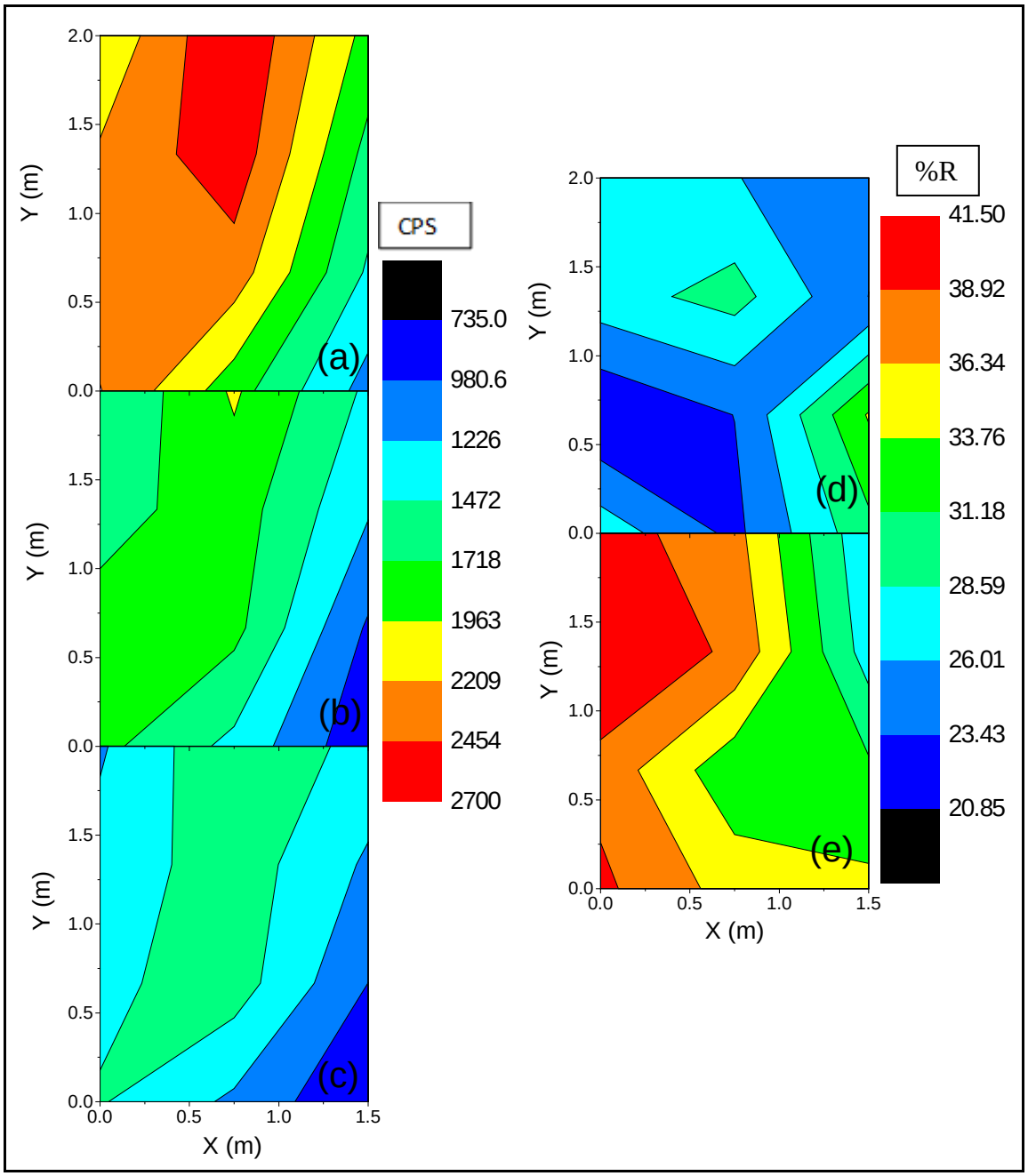


Figure F-6. Contamination measurement results for surface 23 (limestone – EAI Supergel): (a) preliminary contamination level, (b) and (c) contamination levels after the first and second decontamination processes, respectively, (d) and (e) calculated %R values plotted after the first and second decontamination processes, respectively, measured with the NaI(Tl) 2" detector

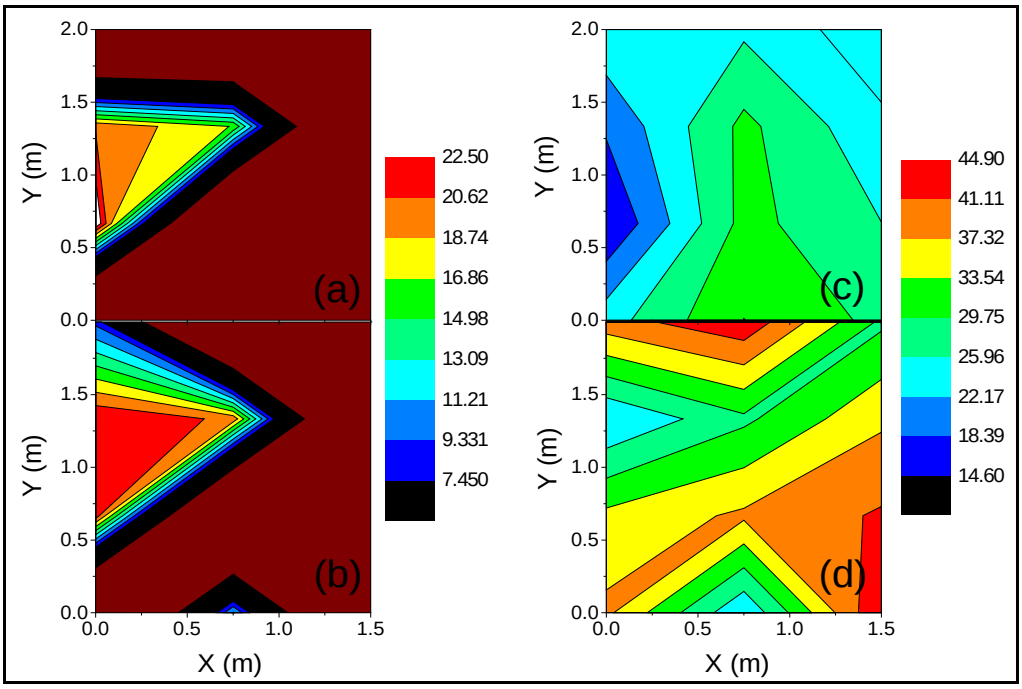


Figure F-7. Calculated %R values of surface 1-1(concrete – DeconGel™), plotted for the PDS-100G/ID (left) and the RAM-SURF (right) detectors, after the first (a), (c) and second (b), (d) decontamination processes (the PDS-100G/ID results for this surface [figures (a) and (b)] are only partially present due to inconsistency of some of the data points taken)

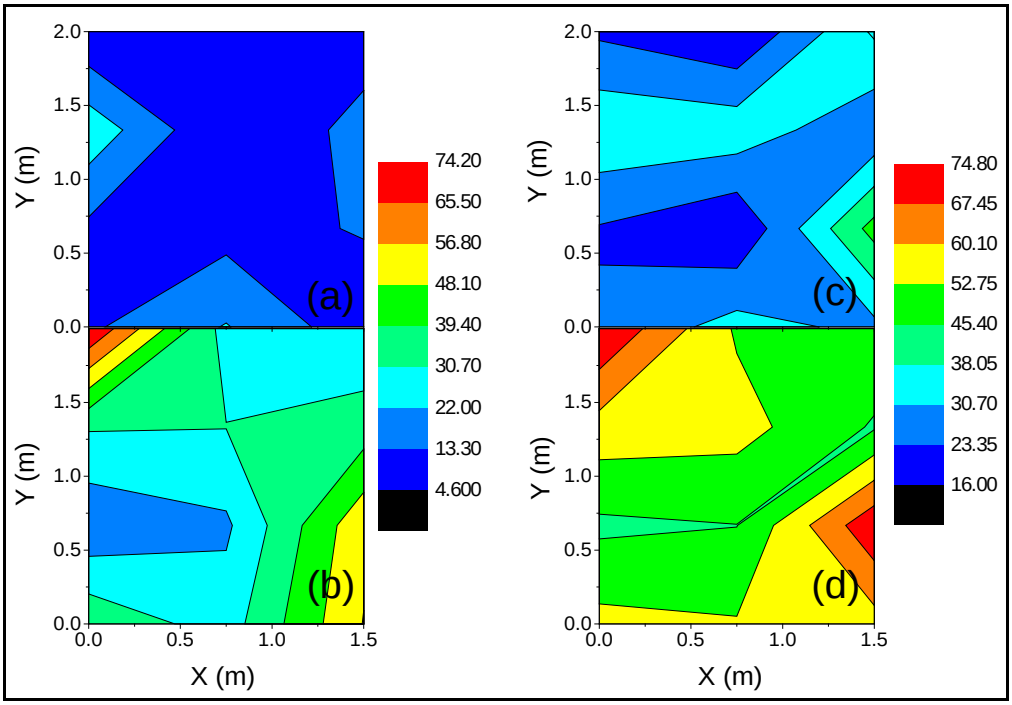


Figure F-8. Calculated %R values of surface 1-2 (marble – DeconGel™), plotted for the PDS-100G/ID (left) and the RAM-SURF (right) detectors, after the first (a), (c) and second (b), (d) decontamination processes

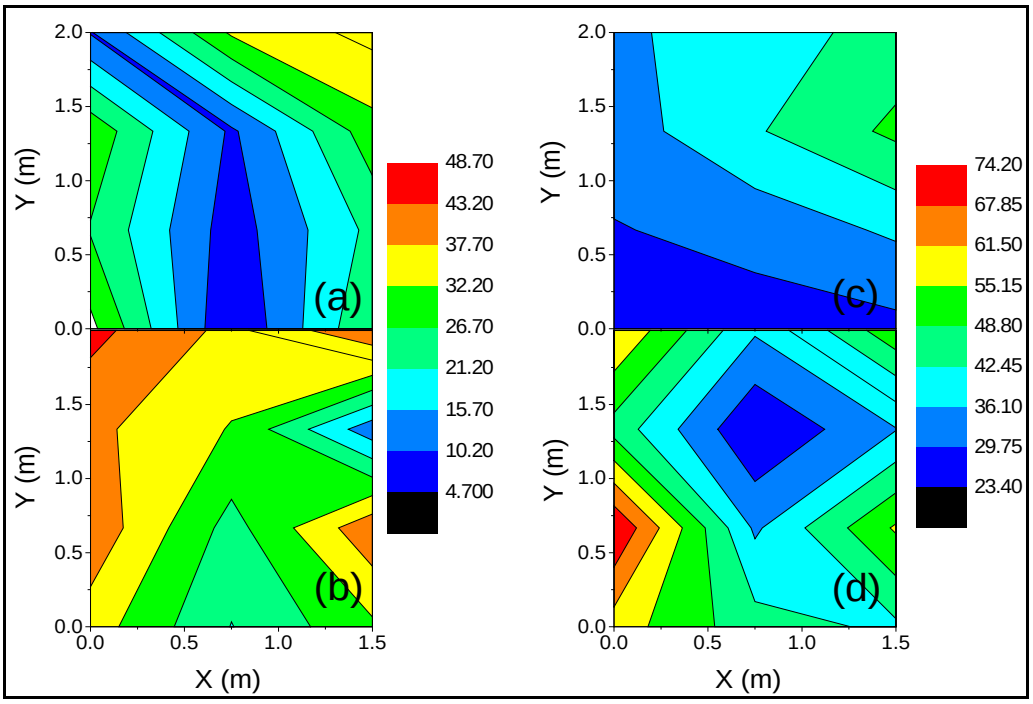


Figure F-9. Calculated %R values of surface 1-3 (limestone – DeconGel™), plotted for the PDS-100G/ID (left) and the RAM-SURF (right) detectors, after the first (a), (c) and second (b), (d) decontamination processes

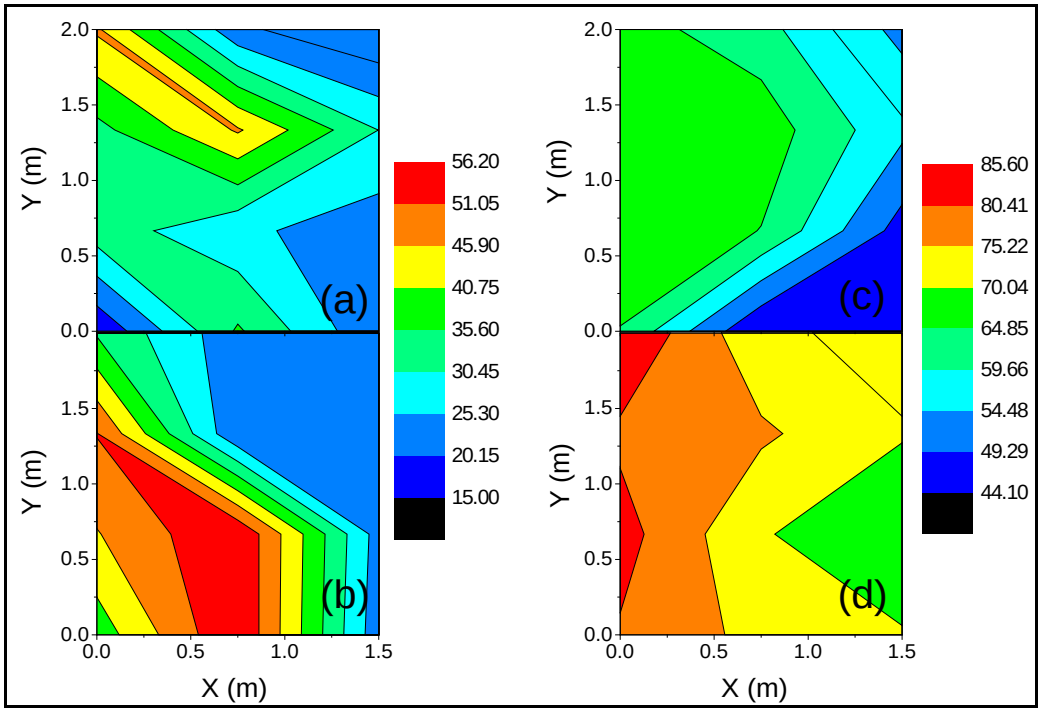


Figure F-10. Calculated %R values of surface 2-1 (concrete – EAI Supergel), plotted for the PDS-100G/ID (left) and the RAM-SURF (right) detectors, after the first (a), (c) and second (b), (d) decontamination processes

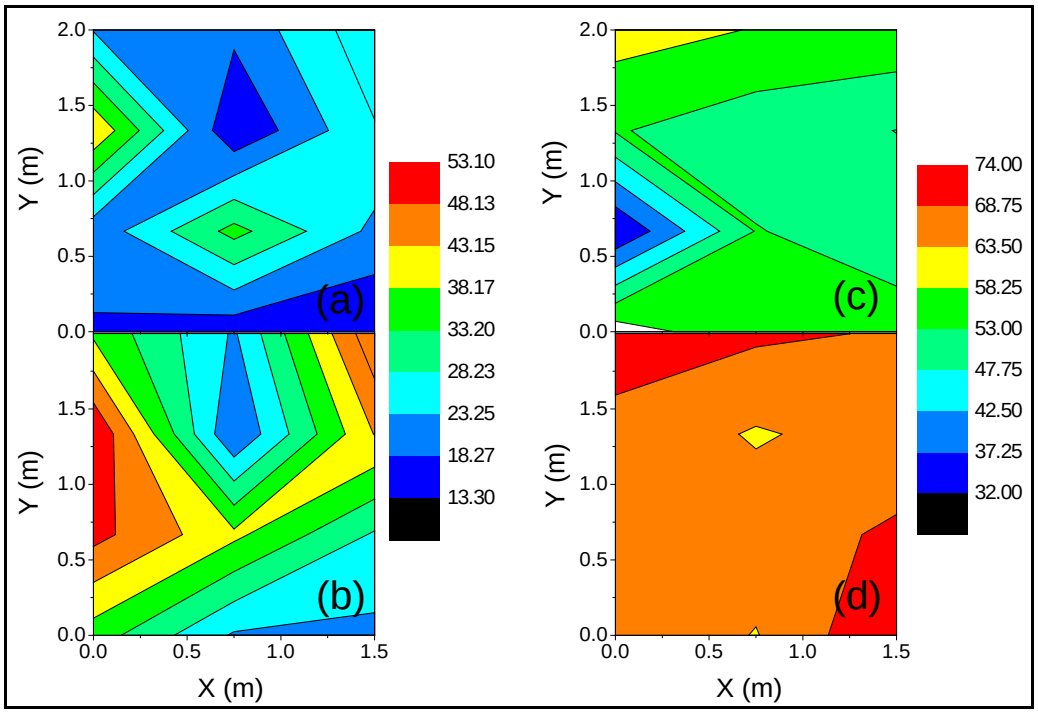


Figure F-11. Calculated %R values of surface 2-2 (marble – EAI Supergel), plotted for the PDS-100G/ID (left) and the RAM-SURF (right) detectors, after the first (a), (c) and second (b), (d) decontamination processes

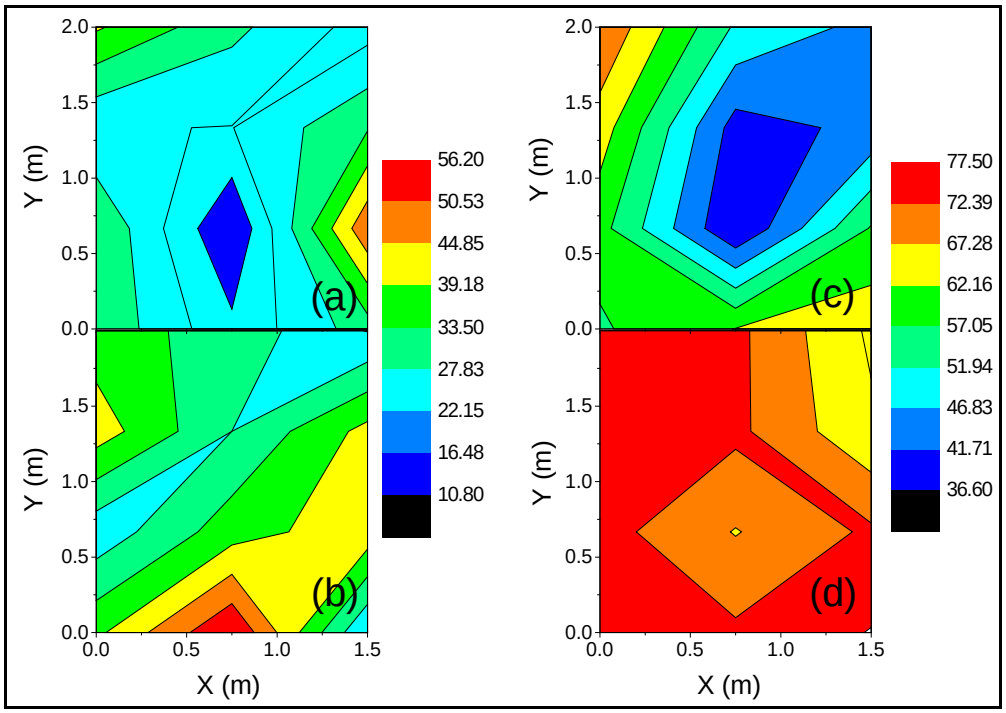


Figure F-12. Calculated %R values of surface 2-3 (limestone – EAI Supergel), plotted for the PDS-100G/ID (left) and the RAM-SURF (right) detectors, after the first (a), (c) and second (b), (d) decontamination processes

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